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AN ALGORITHM FOR THE SCHEDULING OF VESSELS
THROUGH THE PANAMA CANAL

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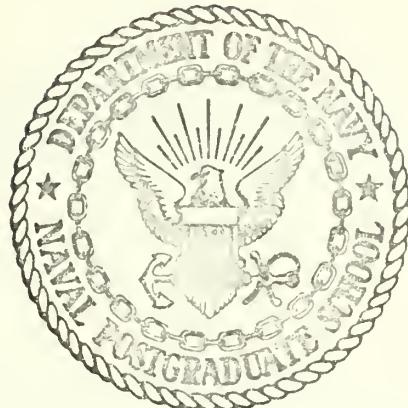
THESIS

AN ALGORITHM FOR THE SCHEDULING OF VESSELS
THROUGH THE PANAMA CANAL

by

Robert James Norman, Jr.

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September, 1973

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An Algorithm For the Scheduling of Vessels

Through the Panama Canal

by

Robert James Norman, Jr.
Lieutenant, United States Navy
B.S., United States Naval Academy, 1965

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

ABSTRACT

This thesis presents an algorithm for scheduling vessel transits

through the Panama Canal together with a compilation of current Marine

Traffic Control scheduling practices. The performance of the scheduling

algorithm is compared with the results of an actual transit schedule using

the Panama Canal Company Marine Traffic Control scheduling objectives

and additional measures of effectiveness derived in this paper.

The interaction between these measures of effectiveness is discussed

as pertains to their future use in the efficient scheduling of vessels through

the canal.

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TABLE I. GLOSSARY[1]

Actual Schedule: The transit schedule contained in a Transit Operations
Sheet and used in this paper to compare against the derived schedule.

Available Lane: A lock lane is considered available when the vessel oc-
cupying the lane has departed and the vessel's lockage interval has
elapsed.

Available Vessel: A vessel is considered available to start transit of the
canal when clock time reaches the vessel's ready time. A vessel is
considered available to transit a lock if the vessel's loco requirement
does not exceed the available lock lane's loco capability and the ves-
sel is next in the order of vessels, timewise, waiting to transit the
lock.

Beam Rule (170 foot beam rule): Vessels with a beam width of between 91
feet and 95 feet may meet vessels in the opposite direction in Gail-
lard Cut if the combined beams of the two vessels do not exceed 170
feet and neither vessel is a Clearcut vessel.

Canal Zone Waters Time: A vessel's elapsed time from the time the vessel
has been reported ready for transit until it has completed its transit.

Chamber: The portion of a lock within which a vessel remains while being
raised or lowered. Pedro Miguel lock has one chamber per lane,

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[1]Parts of this glossary have been compiled from the Marine Traffic
Control Manual, Panama Canal Company, 1971.

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Miraflores lock has two chambers per lane and Gatun lock has three chambers per lane.

Clear Channel (CCh): The restriction placed on certain vessels wherein they cannot meet a vessel in the opposite direction in channels at the entrance to the canal.

Clearcut (CC): The restriction placed on certain vessels wherein they cannot meet a vessel in the opposite direction in Gaillard Cut.

Culverts: Large ducts through which water flows to fill or empty lock chambers. Lock transit times depend on assignment of culverts to the lock chambers.

Cut Conflict: A clearcut vessel meets a vessel in the opposite direction in the Cut.

Daylight Transit (DL): The restriction placed on certain vessels wherein they must transit all locks during daylight hours.

Delay Time: The number of minutes elapsed time that a vessel is delayed during transit of the canal.

Derived Schedule: A schedule of vessel transit times resulting from the use of the Scheduling Algorithm.

Double Barrel Operation (DB): The practice of scheduling both lanes of a lock for transits of vessels in the same direction.

Handline: Lockage of a vessel too small to require locomotives.

Initial PM Conflict: The transit time interval of two vessels in opposite directions overlaps at PM lock.

Intransit Time: A vessel's elapsed time to transit the canal from entering the first set of locks until clearing the last set of locks.

Lane: Each lock has parallel sets of chambers providing for two lane operations.

Lock: The structure containing two lanes with one or more sets of chambers in each lane designed for lifting or lowering vessels from one body of water to another.

Lockage: The complete passage of a vessel or group of vessels transiting as a unit through all lock chambers in a lock lane.

Lockage Interval: The elapsed time between the start of lockage of one vessel until the lock lane is available to receive the next vessel.

Lock Dead Time: The number of minutes elapsed time between the completion of the lockage interval of one vessel at a lock lane and the arrival of the next vessel at that lane.

Lock Locomotive Capability: The number of manned locomotives available at each lane of a lock.

Lock Transit Time: The elapsed time between the start and completion of a vessel's lockage.

Locomotives: Electrically-powered engines running on rail tracks along both sides of a lane for the purpose of towing and controlling a vessel throughout its lockage. Vessels may require four, six or eight locomotives depending on size.

PM Conflict: Two vessels in opposite directions scheduled to transit PM lock with overlapping transit time intervals and only one lane available.

Ready Time: The time that an arriving vessel completes customs, quarantine and admeasurement inspections, fueling and cargo transfer and is declared ready for transit.

Regular Lockage: The use of one set of locomotives to handle lockages in a lock lane.

Relay Lockage: The use of two sets of locomotives to handle lockages in a lock lane.

Tandem Lockage: A lockage in which two vessels occupy the same chamber at the same time.

Tie-up: Vessels may be required to delay their transit by tying up to the center approach wall at a lock prior to entering the lock or after completing lockage.

Transit Operations Sheet (TOS): The form which Marine Traffic Control schedulers fill out after the completion of vessel transits for a particular day showing actual vessel transit times through various sections of the canal.

Wires: Each locomotive is secured to the transiting vessel in a lock lane by one or two wires (wire rope). Four to twelve wires may be required on a particular vessel.

I. INTRODUCTION

A. IMPORTANCE OF THE PANAMA CANAL

The Panama Canal Zone is a ten-mile wide strip of land across the Isthmus of Panama ceded in perpetuity to the United States by the government of the Republic of Panama in 1903. The Panama Canal runs through the Canal Zone southward from the Atlantic Coast city of Cristobal to the Pacific Coast city of Balboa.

The importance to United States commerce of the Panama Canal cannot be understated. Approximately 70 per cent of cargoes transiting the Panama Canal either originate in or are destined for the United States. In addition, more than 40 per cent of the ocean trade of South American countries passes through the canal. Finally, the canal is used by almost every country in the world in varying capacities.[2]

The Panama Canal presently averages about 15,000 vessels per year (41 vessels per day) and the future saturation limit of the canal has been estimated to be about 26,800 transits per year (73 vessels per day).[3] Various studies conducted on the world-wide usage of the Panama Canal indicate that saturation of the canal will not occur until 1990 or later.[4] In this regard, the building of a proposed new canal notwithstanding, the Panama Canal will be a viable factor in world commerce, especially on the American continent, for many years to come.

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[2]U.S. Atlantic-Pacific Interoceanic Canal Study Commission, Interoceanic Canal Studies, 1970, p.7.

[3]Ibid., p. 48.

[4]Ibid., p. 21.

B. DESCRIPTION OF THE PANAMA CANAL

The existing Panama Canal consists of short sea-level approaches to an elevated center section formed by the 21 mile long Gatun Lake consisting of fresh water fed by the Chagres River flowing from the interior of the Republic of Panama. The lake is maintained between 81 and 87 feet above sea level depending on the availability of water. This height is the total lift which a vessel must make during the transit of the canal.

On the Atlantic side of the canal is Gatun lock consisting of two parallel lanes with three lift chambers per lane which lift southbound vessels from sea level to Gatun Lake and lower northbound vessels from Gatun Lake to the Atlantic Ocean.

On the Pacific side of the canal are two sets of lock structures. Miraflores lock consists of two parallel lanes with two lift chambers per lane which lift northbound vessels from sea level to Miraflores Lake and lower southbound vessels from Miraflores Lake to the Pacific Ocean. Miraflores Lake is an intermediate body of fresh water which is maintained at an approximate elevation of 54 feet above sea level and is fed by Gatun Lake through Pedro Miguel lock which is the final lock in the canal. Pedro Miguel lock consist of two parallel lanes with one lift chamber in each lane which lifts northbound vessels from Miraflores Lake to Gaillard Cut and lowers southbound vessels from Gaillard Cut to Miraflores Lake.

Gaillard Cut is a seven-mile long , 500 foot wide passage excavated through hilly jungle across the continental divide to connect the Atlantic and Pacific sections of the canal.

A diagram of the 43 mile long canal is provided as Figure 1. This diagram shows a range of transit times for each section of the canal and a range of lockage intervals, the elapsed time between the start of lockage of one vessel until the lock lane is available to receive the next vessel, for each set of locks.

Average Intransit time, a vessel's elapsed time from entering the first set of locks until clearing the last set of locks, is seven hours. Individual vessel Intransit times depend on vessel size and delays encountered while in transit. Canal Zone Waters time, the elapsed time from the time a vessel has been reported ready for transit until it has completed its transit, may vary from 12 to 24 hours for a typical vessel.

C. VESSEL ARRIVAL REQUIREMENTS

Vessels desiring to transit the Panama Canal notify canal authorities 48 hours in advance of their expected arrival time and again when approximately 90 miles distant from Canal Zone jurisdictional waters. This procedure is designed to allow advance preparation of schedules and preliminary planning of daily canal usage.

Upon arrival in Canal Zone waters the vessel is anchored and met by boarding officers for customs and quarantine clearance. In addition, depending on any structural changes subsequent to the vessel's last canal transit, admeasurement personnel determine the need to measure the vessel for determination of toll charges. The entire inspection procedure exclusive of the possible need for admeasurement is accomplished within

Figure 1. Diagram of the Panama Canal[5]

[5] Adapted from a drawing in the Marine Traffic Control Manual, Panama Canal Co., p104.
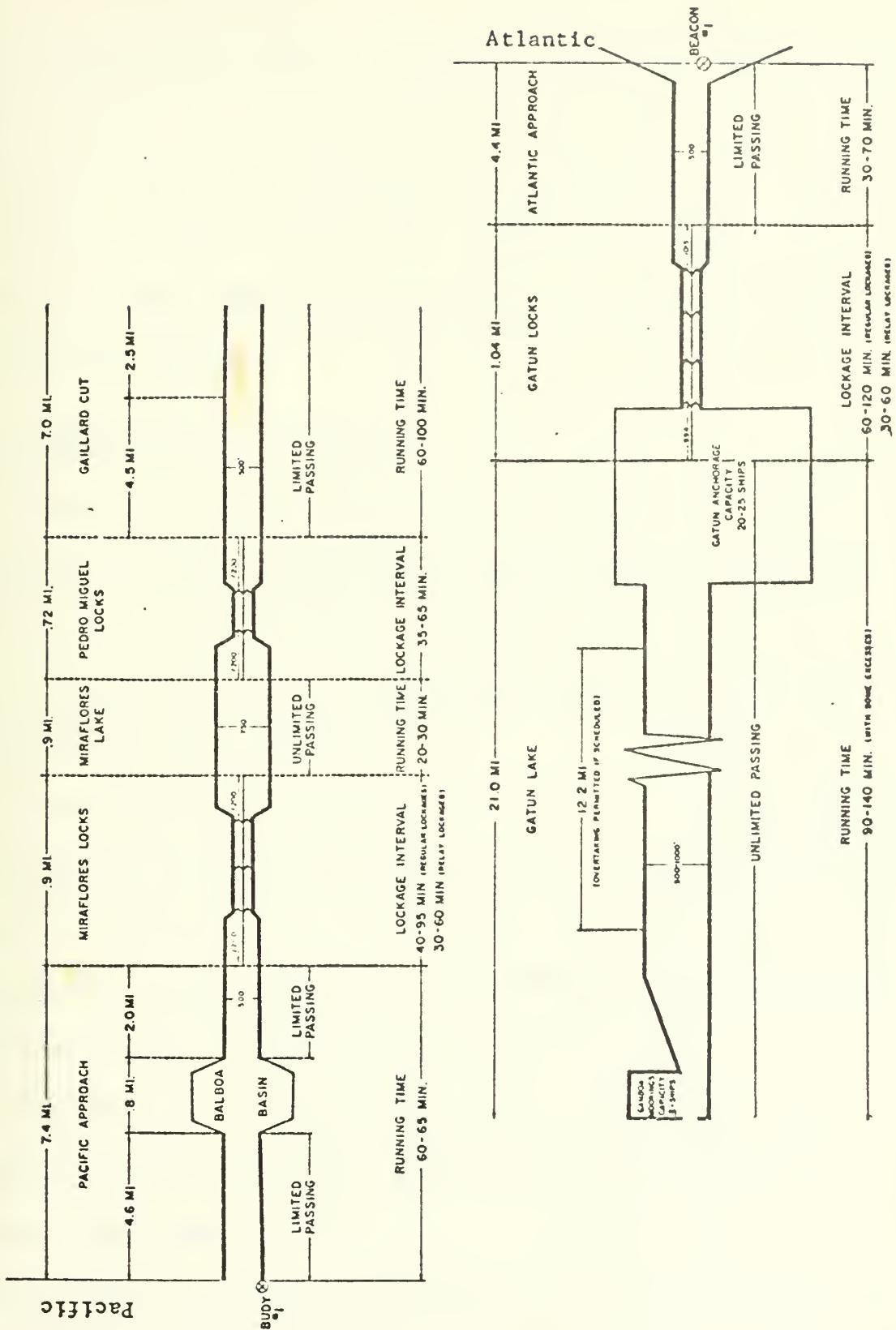
30 minutes and the vessel is then declared ready for transit unless dock-
ing for fuel or cargo transfer is necessary. Depending on transit volume,
vessel arrival and ready time, and mix of vessels awaiting transit, the
vessel may begin transit immediately or be required to wait at anchor un-
til its turn is reached. Usual delays at anchor while awaiting transit are
from four to eight hours although some may be as small as a few minutes
to as long as 70 hours.

D. VESSEL SCHEDULING OVERVIEW

Scheduling of all transits through the Panama Canal is presently ac-
complished manually. Marine Traffic Control Schedulers (MTCS) are
tasked with maintaining a projected schedule 36 hours in advance of
actual transits and updating and revising this schedule to reflect the
actual status of canal operations.

Vessels are normally scheduled on a "first ready, first served" basis
with exceptions at the discretion of the MTCS. The MTCS are also con-
strained by numerous restrictions and requirements placed on transits of
vessels due to size, type of cargo and other considerations intended to
ensure the safety of all transiting vessels and the canal.

Since the MTCS are normally constrained by the order of vessel
arrivals and ready times at the canal there is no real possibility of de-
veloping "the" optimal schedule for a particular mix of vessels awaiting
transit. However, there are many decisions which must be made during
the actual scheduling of vessels in both directions through the various

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sections of the canal which can make one schedule better than another

for a particular mix of vessels. The difficulty of making these decisions

is considerable since the final result of any given decision cannot, in

many instances, be known without completing the schedule. There are

presently no published procedures for the use of the MTCS in making these

decisions. Current Marine Traffic Control practice is to rely on the in-

sight and experience of the schedulers to produce an efficient and practi-

cal schedule.

E. OBJECTIVE OF THIS REPORT

This report describes an attempt to develop some practical scheduling

guidelines and measures of effectiveness and to provide a written proced-

ure, in the form of an algorithm, for the scheduling of shipping through

the Panama Canal.

II. CURRENT VESSEL SCHEDULING PROCEDURES

A. VESSEL SCHEDULING OBJECTIVES

The scheduling objectives under which the Marine Traffic Control Schedulers process traffic through the Panama Canal are:

(1) Obtain maximum lockage capacity in the lock of least capacity consistent with demand.

(2) Obtain the lowest possible Intransit time and Canal Zone Waters time for each vessel.

(3) Maintain a reasonable balance between northbound and southbound shipping transiting the canal.

(4) Process traffic without overtime at the locks as much as possible consistent with demand.

Normally the lock of least capacity is Gatun lock with an average transit time of one hour between vessels in either lane. The first objective may, of course, operate on one of the other sets of locks if a lane is inoperative for maintenance or a casualty or during situations of reduced crewing of locomotives at one of the locks necessitating single lane operation. In general, Marine Traffic Control Schedulers endeavor to maintain the lock of least capacity fully scheduled with no slack or dead time.

In many cases there is a large difference between Instransit time and Canal Zone Waters time for each vessel transiting the canal. Much

of this difference is due to the need to delay some vessels much past
their ready times in order to provide a schedule which is better for the
majority of vessels. These delays are necessitated by current canal
operating conditions and restrictions placed on specific vessels due to
safety considerations.

Depending on traffic demand an effort is made to maintain approxi-
mately the same number of northbound and southbound vessels transiting
the canal in a given scheduling period. The effect of an unbalanced
schedule when traffic demand is the same in each direction is obvious.
Objective (3) also contributes to obtaining the lowest possible Canal
Zone Waters times for each vessel.

Locks are normally manned by sufficient locomotive crews for six
locomotives in each lane. Additional personnel are required for the
transit of eight-locomotive vessels and are considered overtime crews.
In addition, the possibility of securing one lane at a lock when traffic
demand permits is also a factor. In-as-much as an inefficient schedule
contributes to increased personnel costs due to the need to maintain
additional personnel for longer periods than would otherwise be neces-
sary objective (4) is a valid consideration.

B. PANAMA CANAL OPERATING RESTRICTIONS

1. Assignment of Vessel Classes, Restrictions and Requirements

Marine Traffic Control Schedulers operate under the "first ready,
first served" rule. However, in scheduling certain classes of vessels,

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the time of day of the vessel's transit becomes a factor in its scheduling.

In addition, the time of transit of certain portions of the canal for some

classes of vessels in relation to the transit of this portion of the canal

by other vessels must become a consideration.

Appendix A provides a table of vessel restrictions and require-

ments for the safe and orderly transit of the canal. Controlling restric-

tions on vessels are length, beam, draft and type of cargo, with vessels

in excess of 1,000 feet in length, 110 feet in beam and 41 feet in draft

excluded from transit. These figures are the dimensions of the individual

lock chambers of all the locks. Appendix A is utilized by entering the

table with vessel length, beam and, in some cases, cargo on board.

Operative restrictions and canal transit requirements are listed horizon-

tally across the table with appropriate notes printed below the table.

A Clearcut-designated vessel, for example, must not meet other vessels

while transiting Gaillard Cut. The Marine Traffic Control Scheduler will

schedule the start of this particular vessel based on factors such as the

mix of vessels requiring transit, when Gaillard Cut will be available to

this vessel for transit with the least disruption of other traffic and lockage

requirements of this vessel and other vessels at Pedro Miguel lock.

2. Timing of Vessel Transits

Appendix B provides a table of lockage intervals and transit

times for the three locks and other sections of the canal. The table of

transit times is entered using vessel beam and draft information and

whether the vessel is part of a tandem pair in which two vessels occupy

the same lock chamber at the same time. Marine Traffic Control Sched-

ulers use the times given in Appendix B to schedule individual vessels

through each section of the canal.

3. Lockage Procedures

There are two methods of transiting vessels through the locks

in the canal. The Regular lockage procedure is a method whereby one

set of locomotives controls a vessel's transit through all chambers of

the lock. Under Relay lockage procedures two sets of locomotives are

required and the vessel is handed off from one set of locomotives to the

other in the middle lock chamber. Although an additional set of loco-

motives is required in order to relay vessels through a lock, two vessels

can be in the lock at the same time. Relay lockages are utilized only to

transit several vessels in the same direction. Due to the single chamber

construction of Pedro Miguel lock, Relay procedures are not utilized at

that lock.

Appendix C, Figure 5, depicts the mechanics of the lockage pro-

cedure for both Regular and Relay lockages. Tables XII and XIII illustrate

the utilization of Appendix B, tables of lockage intervals and transit

times, under Regular and Relay lockage procedures respectively. Particu-

lar attention should be given to the difference between lockage interval

and lock transit time as used in these tables.

4. Locomotive Requirements

Locomotives (locos) are electrically-powered engines which run

on rail tracks along both sides of a lock lane. Locos are used to tow and

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control vessels while transiting each set of locks since, in most cases,
vessels do not use their own propulsion plant while inside a lock chamber.
There are normally 19 locos available at each lock, however, the number
of locomotive operators assigned varies with traffic intensity and canal
operating conditions. The number of manned locos available in a lock
lane limits the size of vessel, based on loco restrictions in Appendix A,
allowed to transit in that lane as shown in the following table.

TABLE II. LOCOMOTIVE REQUIREMENTS[6]

Type of Lockage	No. of Locomotives in a Lane	Lockage Limitation
Regular	4	Only four locomotive vessels.
Regular	6	All vessels except tandems.
Regular	8	None.
Relay	8	Only four locomotive vessels.
Relay	10	All vessels except tandems or two consecutive six locomotive vessels.
Relay	12	All vessels. Tandems must be followed by a four locomotive vessel.
Relay	16	None.

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[6]Compiled from data in the Marine Traffic Control Manual, Panama
Canal Company, p. 84.

The number of locomotive operators in one lane may be supplemented by locomotive operators from the other lane. Sufficient time must be alloted in the schedule for this shift to take place. Required time to shift operators is 30 minutes at Gatun lock and 20 minutes at Miraflores and Pedro Miguel locks.

5. Vessel Delay and Tie-Up Restrictions

Once a vessel is intransit in the canal there are only certain areas where a delay to a vessel may be scheduled. These areas are:

a. Balboa basin (limited to two vessels at anchor).

b. Gamboa moorings (three or four vessels).

c. Gatun Lake (25 vessels at anchor).

d. North or South approach walls of any of the three locks (two or three vessels depending on size).

Tie-ups to a lock-lane approach wall can be utilized to delay vessels while awaiting clearance for the Cut or various channels and to make up tandems for lockage. When tie-ups at a lock-lane approach wall are utilized the usage of that particular lock lane is limited to a vessel or vessels already in the lock-lane chambers and proceding in the same direction.

C. CURRENT VESSEL SCHEDULING MECHANICS

There are currently no written procedures for the Marine Traffic Control Schedulers to schedule vessels through the Panama Canal while adhering to the vessel restrictions and canal requirements described above. The

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difficulty of making scheduling decisions on the basis of these restrictions

and requirements is considerable since the final result of any one given

decision by the scheduler cannot, in many cases, be determined without

fully completing all or at least a great portion of the schedule. To do this

for all possible combinations of vessels requiring transit on a given day

in order to arrive at the optimum schedule would be an extremely time-

consuming process. Instead, the insight and experience of the Marine

Traffic Control Schedulers is relied on to reduce the number of possible

alternatives considered and to produce a practical schedule within the

scope of the Panama Canal scheduling objectives.

A scheduling form (PanCanal Co. 4374) is utilized by the scheduler to

plan his rough schedule of each day's transits through the canal. Using

trial and error, the forms, one for northbound vessels and one for south-

bound vessels, are filled in. During this process changes and alterations

to the schedule are made, as necessary, to avoid or eliminate conflicts

between vessels. The process is completed when canal capacity is reached

or all vessels requiring transit on that particular day are scheduled.

Upon completion of actual vessel transits for a particular day, actual

vessel transit times through various portions of the canal are filled in on

the Transit Operations Sheet (PanCanal Co. 4344). This form provides a

permanent record of vessel transits together with statistics showing in-

dividual vessel Intransit times and Canal Zone Waters times.

A. INTRODUCTION

In studying the algorithm presented, it is helpful to think of the Panama Canal as divided into three sections created by the physical limitations within the canal and also by the restrictions imposed on vessels transiting the canal. These three sections are; (1) the Miraflores/Pedro Miguel (MF/PM) lock complex including the Pacific Channel, Miraflores Lake and the Gaillard Cut, (2) Gatun Lake, and (3) Gatun lock and the Atlantic Channel. The reasoning behind this division is that vessels which have entered the MF/PM lock complex or the Gatun lock complex are normally constrained to continue transit and clear that section so as not to hold up other shipping. Gatun Lake is a natural unrestricted anchorage which may be utilized to delay northbound vessels prior to transit of the Gatun lock complex.

There are several abbreviations which are used in the algorithm. These are:

1. NB – A vessel which begins transit of the canal at Miraflores lock (northbound direction).

2. SB – A vessel which begins transit of the canal at Gatun lock (southbound direction).

3. Gatun(x/y), MF(x/y), PM(x/y) – Lock locomotive crew availability. The letter x represents the number of locomotive crews available in the east lane and the letter y represents the number of

locomotive crews available in the west lane. For example, MF(6/4) means that the east lane at Miraflores lock has sufficient locomotive crews to transit six-loco vessels and the west lane has sufficient locomotive crews to transit only four-loco vessels.

4. NB(6), NB(4), SB(6), SB(4) - Locomotive requirement for a particular vessel in the direction indicated. For example, SB(4) means that this particular southbound vessel requires four locomotives when passing through a lock lane.

5. NB(CC), SB(CC) - This particular vessel in the direction indicated is restricted to not meeting other vessels in the opposite direction in Gaillard Cut (a "Clearcut" vessel).

6. NB(DL), SB(DL) - This particular vessel in the direction indicated is restricted to not transiting any lock during hours of darkness (a "Daylight" vessel).

7. DB - Refers to double barrel operation at a lock. Two vessels transit the lock at essentially the same time, both in the same direction, in "opposite" lanes.

There are also five terms which are used in the algorithm with which familiarity is necessary. These are:

1. Available lane - A lock lane is considered available when the departing vessel's lockage interval has elapsed.

2. Available vessel - A vessel is considered available to start transit of the canal when clock time reaches the vessel's ready

time. A vessel is considered available to transit a lock if the vessel's loco requirement does not exceed the available lock lane's loco capability and the vessel is next in the order of vessels, time-wise, waiting to transit the lock.

3. Cut conflict - A Clearcut vessel meets a vessel in the opposite direction in the Cut.

4. Initial PM conflict - The transit time interval of two vessels in opposite directions overlaps at PM lock.

5. PM conflict - Two vessels in opposite directions scheduled to transit PM lock with overlapping transit time intervals and only one lane available.

Certain assumptions have been made in this paper in order to produce an algorithm which accurately models the canal under modified operating conditions. After satisfactory testing it is felt that additional constraints can then be built into the algorithm for use under unrestricted canal operating conditions. These assumptions are:

1. The scheduling period for each day's transits commences at midnight or when the first lock at each end of the canal becomes available, whichever is later.

2. At the start of each scheduling period (0000 clock time) only SB vessels from the previous period's transits will be passing through the MF/PM lock complex. Only NB vessels from the previous period's transits will be passing through the Gatun lock complex.

3. Only four and six locomotive vessels are considered.

4. Each lock has either a (6/6) or a (6/4) capability.

5. Clear channel vessels are not considered.

6. Vessel tug requirements are not considered.

7. Tandem lockages are not considered.

8. All vessels are assumed to meet the requirements of the 170 foot beam rule in the Cut. This rule is defined in Table I.

9. Vessels are only allowed to delay in Gatun Lake or by tie-up along lock approach walls.

B. ALGORITHM OVERVIEW

The scheduling algorithm starts with a listing of each vessel desiring transit along with the time each vessel was, or will be, ready to start transit, locomotive requirements, vessel beam width for the purpose of computing transit times, special restrictions and other pertinent facts. From the previous period's schedule the time that each lane in each lock will be available to commence transit of vessels in this scheduling period is noted.

The locomotive capability at each lock lane, based on loco crews available at each lock lane, is then indicated on the NB and SB scheduling forms, in the space provided, for reference by the scheduler when creating the schedule.

The first "available" SB vessel is scheduled through Gatun lock, Gatun Lake, the Cut and through PM lock. "Available" NB vessels are next

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scheduled in ready time order, using double barreling procedures when possible, until the current NB being scheduled and thefirst SB vessel scheduled have overlapping transit time intervals at PM lock ("Initial PM conflict").

Once this conflict time has been determined the time that the first NB vessel, scheduled through Gatun Lake, is available at Gatun lock will also have been determined. SB vessels are next scheduled through Gatun lock in ready time order, using double barreling procedures when possible, up to the time that the first NB vessel is available for lockage at Gatun lock.

When this time has been reached NB vessels available in Gatun Lake and SB vessels on the ready time list are scheduled through Gatun lock using a single lane for each direction until the supply of NB vessels in Gatun Lake is exhausted.

At this time there is one NB vessel and the first SB vessel at PM lock and other SB vessels in Gatun Lake available to transit the Cut. The "initial PM conflict" is next resolved between the NB and SB vessels at PM lock. The resolution of the conflict determines lane assignments at PM and MF locks for NB and SB vessels based on the loco requirements of NB vessels ready to start transit of the canal. If the first SB vessel was also involved in a Cut conflict the conflict is now resolved.

Scheduling continues in an iterative process involving the scheduling of vessels through Gatun lock when NB vessels are available in Gatun

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Lake for lockage and the scheduling of vessels through the Cut and MF and PM locks when the supply of NB vessels in the lake is exhausted. Conflicts at the Cut or PM conflicts are resolved as they occur.

Once all NB vessels have transited the canal the final step of the algorithm ensures that all SB vessels complete transit.

Flow charts illustrating the relationships among the steps in the algorithm are provided at various points in the algorithm text.

C. SCHEDULING ALGORITHM

1. List all vessels requiring transit in the same direction in the order of their ready times showing ready times, locomotives required, vessel beam width and special restrictions (Clearcut and/or Daylight) for each vessel. From the previous period's schedule note the time that each lane at MF and PM locks will be available to lock NB vessels (start of lockage of the last SB vessel scheduled through each lane plus the lockage interval for that vessel or midnight, whichever is later). Note the time that each lane at Gatun lock will be available to lock SB vessels (start of lockage of the last NB vessel scheduled through each lane plus that vessel's lockage interval or midnight, whichever is later). Designate on the scheduling form for each direction the loco capability of each lane at MF, PM and Gatun locks. Depending on the number of loco crews available at each lock, possible lock lane loco capabilities are either six or four locomotives.

The earliest lane available should be designated as a six-loco lane at each lock if the six-loco lane is not required for transiting the last vessels on the previous period's transit schedule. Go to step 2.

2. Schedule the first available SB vessel on the ready time list through the earliest available lane at Gatun lock and continue this vessel through Gatun Lake, the Cut and PM lock. DL vessels are not considered available for transit until the vessel's transit start time plus channel running time is greater than or equal to the time of daylight. Go to step 3.

3. Commence scheduling available NB vessels in the order of their ready times through MF and PM locks, the Cut and Gatun Lake.

   a. If one lane at MF and at PM is available earlier than the other lane and they are both six-loco lanes, send as many six-loco and four-loco NB vessels as possible through this lane in each lock without violating any vessel ready times. Go to step 3c.

   b. If one lane at MF and at PM is available earlier than the other and they are both four-loco lanes or one is a four-loco lane, send as many four-loco vessels as possible through this lane in each lock without violating any vessel ready times. Go to step 3c.

   c. If both lanes at MF and PM are available at the same time or when both lanes become available, commence double barreling NB vessels through both locks, the Cut and Gatun Lake. Go to step 3d.

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d. Stop scheduling NB vessels when the time interval of the NB vessel currently being scheduled overlaps the time interval of the first SB vessel scheduled at PM lock or there is a Cut conflict caused by the first SB vessel being a Clearcut (CC) vessel or by any NB(CC) vessel which the first SB vessel's Cut transit time interval overlaps in the Cut. Go to step 4.

4. Schedule the second and subsequently available SB vessels through Gatun lock and Gatun Lake.

a. If one lane at Gatun lock is available earlier than the other and it is a six-loco lane, schedule as many six-loco and four-loco vessels as possible through this lane without violating vessel ready times. Go to step 4c.

b. If one lane at Gatun lock is available earlier than the other and it is a four-loco lane, schedule as many four-loco vessels as possible through this lane without violating any vessel ready times. Go to step 4c.

c. If both lanes at Gatun lock are available at the same time or when both lanes become available, commence double barreling SB vessels through both lanes and through Gatun Lake. Go to Step 4d.

d. Stop double barreling SB vessels at Gatun when the first NB vessel is available to lock at Gatun. Go to step 5.

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5. Assign lanes at Gatun lock based on the loco requirements of vessels in each direction available for lockage. Schedule available NB and SB vessels through Gatun lock. Switch lanes as necessary to allow SB vessels to transit Gatun lock without delay due to loco requirements. NB vessels are to take delays in Gatun Lake while awaiting an available lane at Gatun. NB vessels are not to be delayed due to the double barreling of SB vessels at Gatun lock. Stop scheduling SB vessels into Gatun Lake when the last available NB vessel in Gatun Lake has passed through Gatun lock and finished transit or there are no more SB vessels on the ready time list. Go to step 6.

6. a. If both MF and PM are 6/6 assign one lane at each lock to SB vessels and one lane at each lock to NB vessels. If there is a Cut conflict go to step 7, otherwise go to step 10.

   b. If either MF or PM are 6/4 and:

   (1) There are no more NB(6) vessels remaining on the ready time list or NB(6) vessels are not available to start canal transit, assign the four-loco lanes at MF and PM locks to NB vessels and the six-loco lanes to SB vessels. If there is a Cut conflict go to step 7, otherwise go to step 8.

   (2) If NB(6) vessels are available to start canal transit assign the four-loco lanes at MF and PM to SB vessels and the six-loco lanes to NB vessels. If there is a Cut conflict go to step 7, otherwise go to step 9.

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7. a. If the NB vessel is a CC vessel and the SB vessel available to transit the Cut is not and:

 (1) There is another NB(CC) vessel available to start transit following this NB(CC) vessel; delay the first NB(CC) vessel by tie-up after transit of PM until 10 minutes prior to the finish of transit at PM lock of the following NB(CC) vessel. Schedule as many available SB vessels through PM to the finish of transit as possible prior to the start of transit of the Cut by the first NB(CC) vessel. Schedule the NB vessels through the Cut and Gatun Lake. Go to step 11.

 (2) Another NB(CC) vessel is not available to start transit. Delay the available SB vessel in Gatun Lake until the NB(CC) vessel transits the Cut. Schedule the NB(CC) vessel through the Cut and Gatun Lake. Schedule the SB vessel through PM lock to the finish of transit. Go to step 11.

 b. If the available SB vessel is a CC and the NB vessel is not and:

 (1) If the NB vessel is a DL vessel, delay the SB(CC) vessel in the lake. Schedule the NB vessel through the Cut and Gatun Lake. Go to step 11.

 (2) If the NB vessel is not a DL vessel, delay the NB vessel and any previous NB vessels that had not started transit of the Cut prior to the time the SB(CC) vessel could have started transit. Re-schedule the delayed NB vessels to

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provide for delays at either MF or PM locks. If a second SB(CC) vessel is available to transit the Cut at the same time as the first SB(CC) vessel, even if taken out of order of sequence of SB vessels available in Gatun Lake, both CC vessels should transit the Cut at a 10 minute interval. Schedule the SB(CC) vessel(s) through PM lock to the finish of transit. Schedule the NB vessel(s) delayed at MF or PM locks through the Cut and Gatun Lake. Go to step 11.

c. If both the NB and SB vessels are CC vessels:

    (1) If both vessels have a second CC vessel available for transit delay the first NB(CC) vessel by tie-up after transit of PM lock until 10 minutes prior to the finish of transit at PM of the following CC vessel. Schedule both SB(CC) vessels through the Cut and the finish of transit prior to scheduling the NB(CC) vessels through the Cut and Gatun Lake. Go to step 11.

    (2) If only the vessel in one direction has a second CC vessel available to transit, delay the vessel in the opposite direction until the two vessels complete their transit of the Cut. Schedule the SB vessel(s) through to the finish of transit and the NB vessel(s) through Gatun Lake. Go to step 11.

    (3) If neither CC vessel has a second CC vessel available to transit delay the SB vessel in Gatun Lake. Schedule the NB vessel through Gatun Lake. Go to step 11.

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Figure 2. Algorithm Flow Chart, Part A
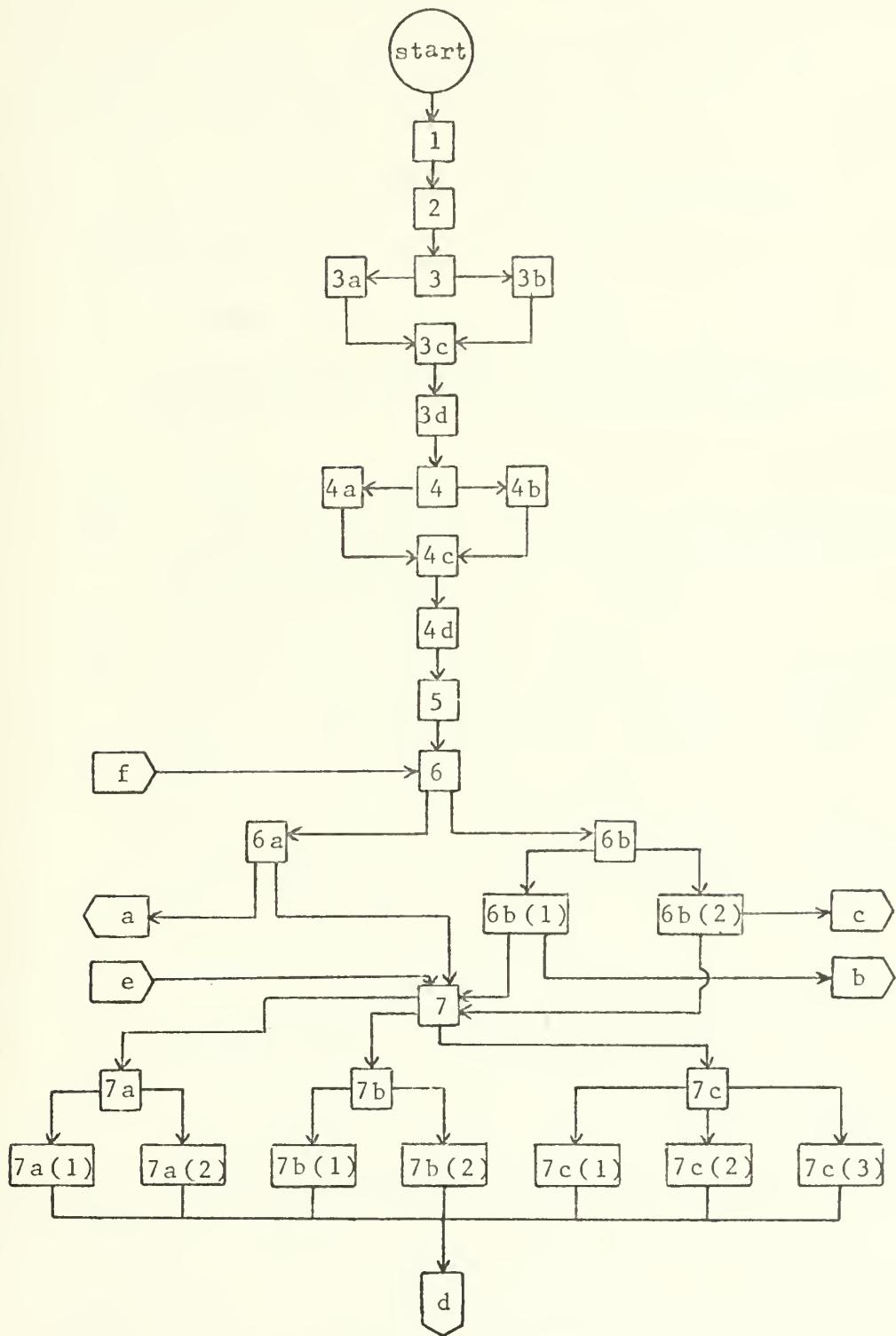
8. If SB vessel(s) at PM lock have not yet been scheduled through the finish of transit, do so. Determine the status of NB vessel(s) at PM lock and the next available SB vessel in Gatun Lake.

   a. If there is not a NB vessel at PM lock, go to step 8c. If there is a NB vessel at PM lock and:

      (1) If there is no SB vessel available in Gatun Lake schedule the NB vessel at PM lock through Gatun Lake. Go to step 11.

      (2) If either the NB vessel at PM or the next available SB vessel in Gatun Lake is a CC vessel, go to step 7.

      (3) If neither is a CC vessel, schedule the SB vessel through the Cut, when the Cut is clear of NB(CC) vessels, to the finish of transit. Schedule the NB vessel through the Cut when the Cut is clear of SB(CC) vessels, and through Gatun Lake. Continue to step 8b.

   b. If the scheduler desires to change lock lane loco capability at MF and PM locks, do so and go to step 6. Also, go to step 6 if a NB(6) vessel on the ready time list is available to start transit. Otherwise, continue to step 8c.

   c. If there is no NB(4) vessel remaining on the ready time list, go to step 11. Otherwise, schedule the next available NB(4) vessel through MF and PM locks in either lane, whichever is available without interfering with SB vessels, with priority given to the four-loco lanes. Return to step 8a.

Figure 3. Algorithm Flow Chart, Part B
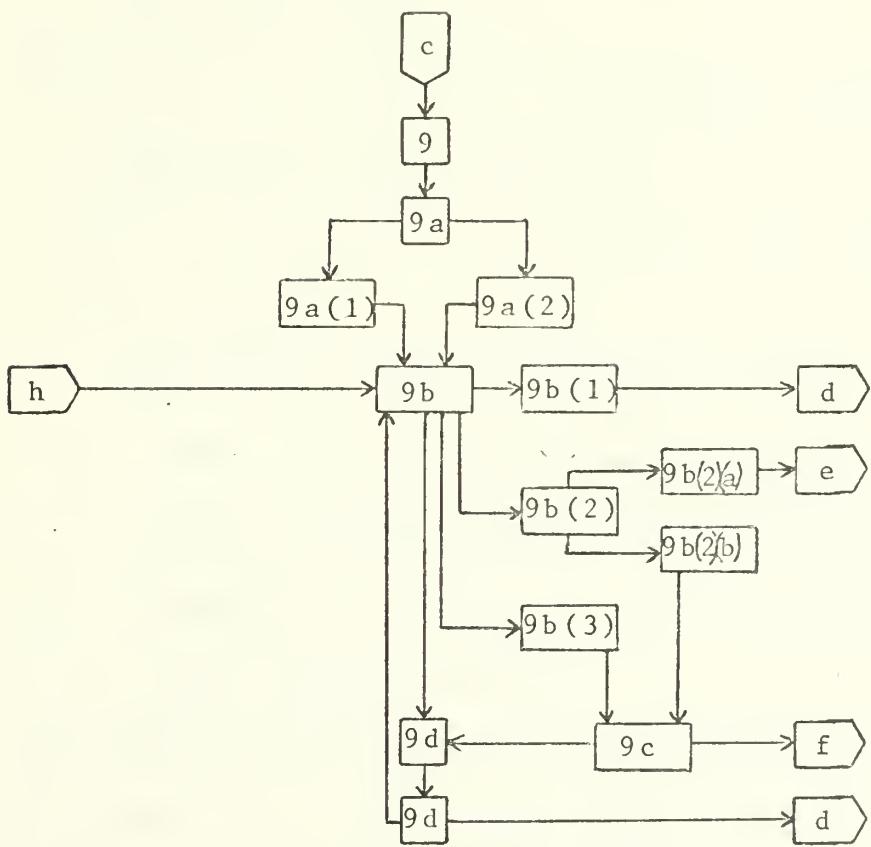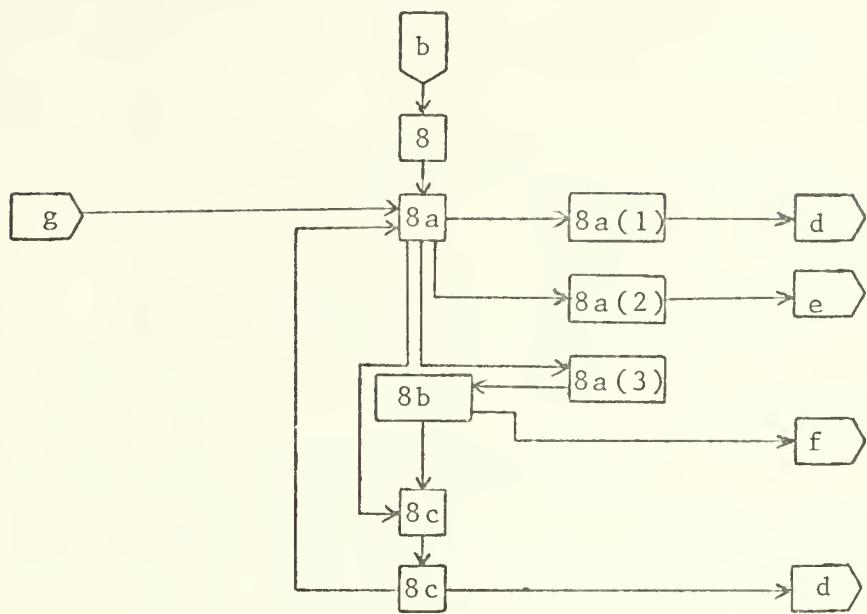
9. a. (1) If the SB vessel(s) in PM lock are four-loco vessel(s),
            schedule them through to the finish of transit. Go to
            step 9b.

        (2) If the SB vessel(s) in PM lock are six-loco vessel(s),
            remove them from PM lock and the Cut. Delay these
            vessel(s) in Gatun Lake. Go to step 9b.

    b. If there is not a NB vessel at PM lock, go to step 9d. If
        there is a NB vessel at PM lock and:

        (1) If there is no SB vessel available in Gatun Lake,
            schedule the NB vessel at PM lock through Gatun
            Lake. Go to step 11.

        (2) If the next SB vessel in the order of finish transit of
            Gatun Lake is a SB(4) vessel and:

            (a) If either this SB or the NB at PM is a CC vessel, go
                to step 7.

            (b) If neither this SB or the NB vessel at PM is a CC
                vessel, schedule the SB vessel through the Cut, when
                the Cut is available, and then to the finish of transit.
                Schedule the NB vessel through the Cut and Gatun
                Lake. Continue to step 9c.

        (3) If the next SB vessel in the order of finish of transit of
            Gatun Lake is a SB(6) vessel, delay this vessel in Gatun
            Lake and schedule the NB vessel through the Cut and
            Gatun Lake. Continue to step 9c.

c. If the scheduler desires to change lock lane loco capability at MF and PM locks, do so and go to step 6. Also go to step 6 if no NB(6) vessel on the ready time list is available to start transit. Otherwise, continue to step 9d.

d. If there is no NB vessel remaining on the ready time list, go to step 11. Otherwise, schedule the next available NB vessel on the ready time list through MF and PM locks in either lane, whichever is available without interfering with SB vessels, with priority given to the six-loco lanes. Return to step 9b.

10. If SB vessel(s) at PM lock have not yet been scheduled through the finish of transit, do so. Determine the status of NB vessels at PM lock and the next available SB vessel in Gatun Lake.

a. If there is not a NB vessel at PM lock, go to step 10c. If there is a NB vessel at PM lock and:

(1) If there is no SB vessel available in Gatun Lake, schedule the NB vessel at PM lock through Gatun Lake. Go to step 11.

(2) If either the NB vessel at PM or the next available SB vessel in Gatun Lake is a CC vessel, go to step 7.

(3) If neither is a CC vessel, schedule the SB vessel through the Cut, when the Cut is clear of NB(CC) vessels, to the finish of transit. Schedule the NB vessel through the Cut, when the Cut is clear of SB(CC) vessels, and through Gatun Lake. Continue to step 10b.

b. If the scheduler desires to change lock lane loco capability at PM and MF locks, do so and go to step 6; otherwise, continue to step 10c.

c. If there is no NB vessel remaining on the ready time list, go to step 11. Otherwise, schedule the next available NB vessel through MF and PM locks in either lane, whichever is available without interfering with SB vessels, with priority given to the lane assigned to NB vessels. Return to step 10a.

11. Assign lanes at Gatun lock based on loco requirements of vessels in each direction available for lockage. Switch lanes as necessary to allow SB vessels to transit Gatun lock without delay due to loco requirements. NB vessels take delays in Gatun Lake while awaiting an available lane. Schedule available NB and SB vessels through Gatun lock. Schedule NB vessels through to the finish of transit and SB vessels through Gatun Lake. Stop scheduling vessels through Gatun lock when there are no more SB vessels on the ready time list or when the last available NB vessel in Gatun Lake has been scheduled through Gatun lock to the finish of transit, then if there are no more NB vessels on the ready time list, go to step 12. Otherwise, if:

a. MF and PM locks are 6/6, go to step 10a.

b. MF and PM locks are 6/4, and:

(1) There are no more NB(6) vessels remaining on the ready

Figure 4. Algorithm Flow Chart, Part C

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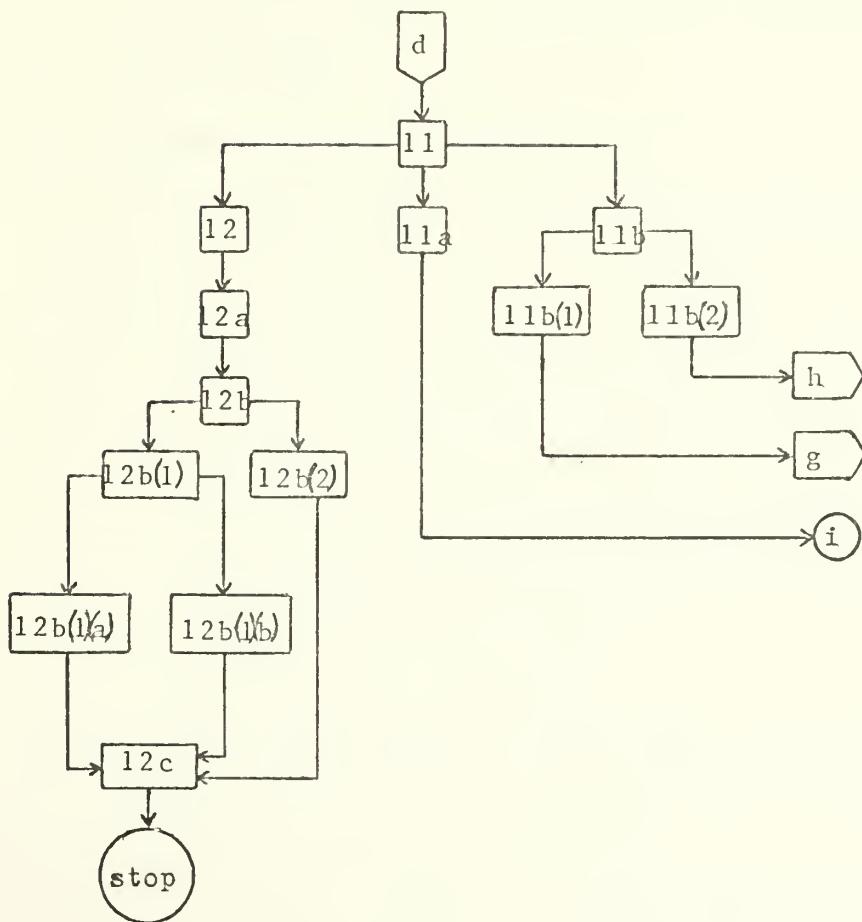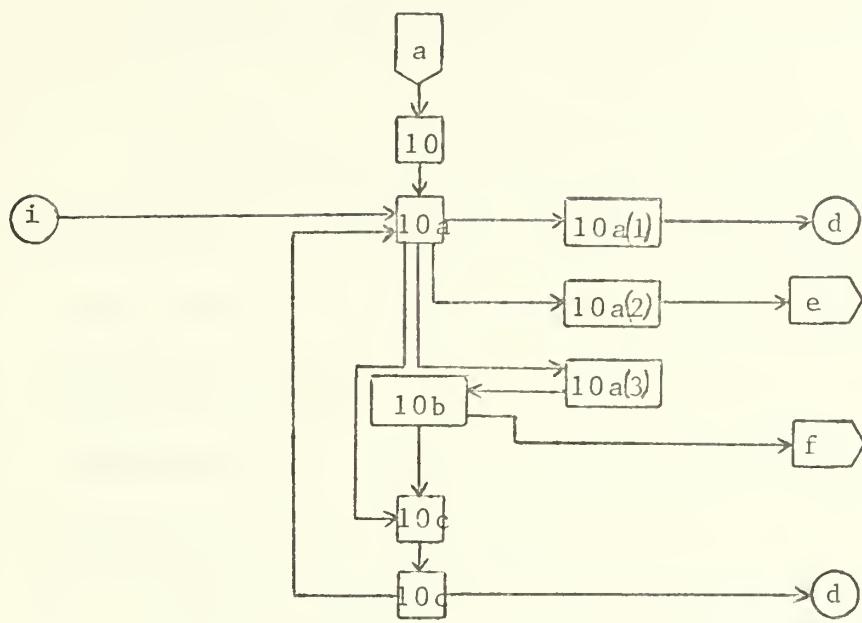
time list or NB(6) vessels remain on the ready time list

but are not available to start transit, go to step 8a.

(2) There are NB(6) vessels remaining on the ready time

list and available to start transit, go to step 9b.

12. a. Schedule any remaining NB vessels in Gatun Lake through

Gatun lock to the finish of transit using DB operation. Con-

tinue to step 12b.

b. Schedule any remaining SB vessels in Gatun Lake through

the finish of transit as follows:

(1) If all SB vessels in Gatun Lake completed transit of the

lake with an interval of 40 minutes or greater between

vessels, and:

(a) None of the vessels is a six-loco vessel, secure

the six-loco lanes at PM and MF locks and schedule

the SB vessels through the four-loco lanes to the

finish of transit. Go to step 12c.

(b) Any of the vessels is a six-loco vessel, secure the

four-loco lanes at PM and MF locks and schedule

the SB vessels through the six-loco lanes to the

finish of transit. Go to step 12c.

(2) If any of the SB vessels in Gatun Lake completed transit

of the lake with an interval of less than 40 minutes be-

tween vessels; schedule the vessels through both lanes

at MF and PM to the finish of transit until:

(a) The remaining vessels in the lake have a 40 minute

or greater interval between vessels. Go to step

12b(1).

(b) No SB vessels remain in the lake. Go to step 12c.

c.   All vessels have completed transit of the canal. Stop.

IV. VALIDATION OF THE SCHEDULING ALGORITHM

A. ACTUAL TRANSIT SCHEDULE

1. Analysis of Transit Data

In order to measure the effectiveness of schedules created by use of the scheduling algorithm, a comparison between an algorithm-created schedule, called the derived schedule, and an actual schedule, utilized for transiting vessels through the canal, was made. In order to make the comparison using a meaningful mix of vessels, transit data from available Transit Operations Sheets (TOS) were analyzed.

The data recorded on the TOS are the actual times of vessel transits and, therefore, should provide an accurate reflection of MTC scheduling practices and categories of vessels utilizing the canal. Only the first 15 of the 31 available Transit Operations Sheets for January, 1972, were utilized because reduction of canal capability due to lane outages during the latter half of the month was considered to provide an inaccurate reflection of scheduling practices and vessel categories.

The 24-hour statistics for the data utilized are presented below:

TABLE III. ANALYSIS OF TRANSIT DATA

Northbound Vessels (NB)	Mean	Standard Deviation
Vessels in 24 hours	14.20	3.33
Six-loco vessels	3.74	1.66
CC vessels	.80	.73
DL vessels	1.87	1.02
Southbound Vessels (SB)		
Vessels in 24 hours	14.30	2.17
Six-loco vessels	4.50	1.78
CC vessels	1.30	1.10
DL vessels	2.94	1.29

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2. Choice of Actual Transit Schedule

Upon completion of the data analysis, the available TOS were searched in order to pick an actual transit schedule which would reflect at least average traffic demand or greater in all four categories described in table III. The TOS for 13 January, 1972, was picked as being most nearly fitted to the requirements specified.

Appendix D presents the actual schedule appearing on the TOS for 13 January, 1972. The scheduling form shown was designed for use in this report and does not represent the Panama Canal Company forms. Transit times appear on this schedule as elapsed times with midnight appearing as zero time in order to allow easier comparison with the derived transit schedule. MTCS use clock times when scheduling vessels through the canal. The data presented were modified slightly to conform to the assumptions stated in Section III of this paper. Tandem lockages are not considered which necessitated the elimination of two NB and three SB tandem pairs from the TOS. Only one ship of each tandem pair was retained in the data presented.

Only vessels in each direction which had completed lockage at the final set of locks by 2400 were considered. This requirement reduced the number of vessels considered for transit from 21 to 16 in the NB direction and from 18 to 15 in the SB direction.

As can be seen from the TOS represented in Appendix D, the following number of vessels in each of the above mentioned classifications transited the canal within the 24-hour scheduling period.

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TABLE IV. ACTUAL VESSEL TRANSITS

	NB	SB
Vessels in 24 hours	16	15
Six-loco vessels	2	5
CC vessels	2	2
DL vessels	4	3

B. DERIVED SCHEDULE USING THE SCHEDULING ALGORITHM

1. Assumptions

Using the same mix of vessels shown in the TOS represented in Appendix D, the scheduling algorithm was employed to schedule the vessel transits of the canal. For the purposes of this example and to conform as nearly as possible to the schedule times for the actual transits of the daylight (DL) restricted vessels, daylight was assumed to begin at 0600 and end at 2000. Values of transit times through the various sections of the canal for each vessel and procedures for calculating Regular lockages were taken from Appendix B with three exceptions:

   a. Individual vessel drafts were not available on the TOS used in the example. Gaillard Cut transit times were assumed to be 60 minutes for NB vessels and 65 minutes for SB vessels.

   b. Individual vessel speed capabilities were not available. All vessels were assumed to have a 10-knot capability and, therefore, could transit Gatun Lake in 120 minutes.

   c. Individual vessel cargo status and drafts were not available. The 90-99 foot row in the table was used for vessels with 90-99 foot beams and the 100+ (laden) row was used for vessels with 100 foot or greater beams.

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All locks were assumed to have a (6/4) capability. This assumption was necessary since information available on the TOS for the actual schedule did not indicate maximum lock lane locomotive capability at any given time.

2. Vessel Designation System

Individual vessels are identified by two methods in the explanation of the use of the scheduling algorithm. The first is by the vessel's precedence in the order of ready times in each direction. For example, the first vessel ready to transit in the northbound direction will be designated as 1N. The distinction between the ready time designation for a vessel and the abbreviation for a particular vessel's locomotive requirement, such as NB(4), should be clear. The second method of designation is by a vessel's transit order in the derived schedule. For example, the first vessel ready to transit in the northbound direction is designated 1N, however, this vessel may not be the first northbound vessel scheduled to transit. If 1N is, in fact, the fifth vessel scheduled to transit, the vessel will be assigned an additional designation as 1N5. A vessel will always have a ready time designation, but will not receive a transit order designation until it has actually been placed on the schedule. Finally, once a vessel has been placed on the schedule, the ready time designation may be dropped for easier reference and the vessel may be referred to by its direction and transit order (i.e., N5).

3. Use of the Scheduling Form

The scheduling form shown in Appendix D embodies most of the

information contained on the Panama Canal Company Transit Operations Sheet with some modification to facilitate the use of the scheduling algorithm. The form can be used for both northbound or southbound vessels and, when scheduling, one form is used for each direction. Northbound vessels are scheduled from left to right and southbound vessels from right to left.

The Ready Time Order (R.T. ORD.) column is filled in as vessels are scheduled to facilitate cross reference to the list of vessels in their order of ready times in step one of the algorithm. The Transit Order (TR. ORD.) is already filled in since vessels are scheduled from top to bottom on the form.

The remarks column is available for showing any special restrictions of the vessel being scheduled, such as a Clearcut or Daylight designation or special cargo being carried.

A vessel's beam width is entered in the appropriate column for use with Appendix B in determining the vessel's transit times through various sections of the canal.

Vessel locomotive requirements are entered in the designated column to facilitate scheduling of vessels through the appropriate lane at each set of locks.

Both east and west lock lanes at each set of locks have a space for designating the lane's locomotive capability in accordance with step one of the algorithm.

The Ready Time (R.T.) column is used to fill in the time the vessel was actually ready to commence transit. This time is used to compute Canal Zone Waters Time.

Once the schedule has been completed, each vessel's Intransit Time (I.T.Time) and Canal Zone Waters Time (C.Z.W.Time) is computed for statistical purposes and placed in the last two columns of the form.

The body of the Scheduling Form is used for recording the transit times through the various sections of the canal for each vessel being scheduled. For ease in scheduling, elapsed times in minutes are used with zero time as 0000 clock time and 1440 minutes as 2400 clock time. Vessel arrival and departure times through each section of the canal are entered in the appropriate space on the scheduling form as determined by the transit times for the vessel being scheduled which are contained in Appendix B. Any delays to the vessel in a specific section of the canal are indicated by a small oval, containing the value of the delay, drawn above the vessel's transit time through that section of the canal.

4. Derived Schedule

The same mix of vessels shown on the actual schedule, as regards the vessel classifications discussed in section IV-A-2, were used in illustrating and validating the scheduling algorithm. All times used in illustrating the algorithm are elapsed times with time zero as 2400 clock time.

Step one of the algorithm requires a listing of vessels to be scheduled in the order of their ready times along with other pertinent

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information. This listing is illustrated in Table XVI in Appendix E. The notation in the remarks column of the table indicates that MF lock is available to transit vessels at time zero in the east lane and time 180 in the west lane. Both lanes at Gatun lock are available to transit vessels at time 180. This information was obtained from the previous day's TOS. In actual practice it would be taken from the previous day's schedule.

Lock lane loco capability is indicated in the appropriate spaces on the NB and SB scheduling forms illustrated in Tables XVII and XVIII in Appendix E. All locks are assumed to have (6/4) capability and by inspection of the previous day's schedule the earliest lanes available in each lock would be designated as six-loco lanes by the algorithm.

In step two the first available SB vessel in the ready time list is scheduled through Gatun lock, Gatun Lake, the Cut and PM lock. It is 4S since the previous vessels on the ready time list are all DL's. This vessel is scheduled to arrive at Gatun lock at time 180 to transit either lane since both are available at this time and 4S is a four-loco vessel. The vessel's transit times through each section of the canal are computed using the vessel's beam width and Table X in Appendix B.

Available NB vessels are next scheduled, using step 3b, through MF and PM locks, the Cut and Gatun Lake using the six-loco lanes since these lanes were the earliest lanes available at each lock. Vessel 1N is not available for transit since it is a DL. Vessel 2N is scheduled through MF lock starting at time zero, the earliest time this lock is available; 3N, 4N and 5N follow. At time 180 step 3c is used since both lanes at

MF and PM are now available. Vessel 6N is scheduled through the four-loco lanes since it is a four-loco vessel. Vessel 7N is not available for transit since it is a DL vessel. Vessel 8N is scheduled following 6N. Vessel 9N is not available since it is a DL. Vessel 10N is scheduled following 8N. Although 10N overlaps the time interval of 1S in the Cut there is no Cut conflict since neither vessel is a CC vessel. The next vessel available to start transit is 1N since 11N is not ready to start transit until time 300 and daylight occurs at time 360. 1N would then be able to start transit earlier than 11N to arrive at MF lock to begin lockage at time 360. Although 1N is a four-loco vessel it is scheduled through the six-loco lanes at MF and PM since they are next available. In accordance with step 3d, scheduling of NB vessels stops with 1N at PM lock since the time intervals of 1N and 4S overlap at PM. It should be noted that there is no actual conflict between these two vessels since the lock loco capability can handle both vessels in opposite lanes simultaneously.

At this time seven NB vessels have transited the Cut and are in Gatun Lake awaiting transit of Gatun lock. Using step 4c, since both lanes at Gatun lock are available at time 180, SB vessels are scheduled through both lanes and through Gatun Lake. Vessel 4S has already been scheduled through the six-loco lane although the choice was arbitrary. Vessel 5S is the next vessel available and it is scheduled through the four-loco lane. Vessel 6S is then scheduled through the six-loco lane. The first NB vessel, 2N1, is available to lock at Gatun at time 275 and double barreling of SB vessels is stopped using step 4d. If another SB

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vessel had been scheduled through the next available lane N1 would have had to be delayed unnecessarily in Gatun Lake.

Using step 5, SB and NB vessels are scheduled through Gatun lock in appropriate lanes until there are no more NB vessels remaining in Gatun Lake for transit. After 7S transits Gatun lock DL vessels are eligible to start transit. Vessels 1S, 2S and 3S follow 7S through the six-loco lane. Ready time order is then resumed with 8S and 9S transiting the lock. Vessel 9S is the last SB vessel to transit the lock since the last NB vessel passed through the lock at time 720.

Step 6 resolves the "initial PM conflict" between 4S and 1N by assigning lock lanes based on NB vessel requirements and directing the scheduler to the next step. Step 6b(2) is used since 9N is available to start transit and is a six-loco vessel. The four-loco lanes are assigned to SB vessels and S1 is placed in the four-loco lane at PM. Since there is no "Cut conflict" at this time the scheduler is directed to step 9.

Using step 9a(1), S1 is scheduled through to the finish of transit. Vessel N8 is presently in PM lock and the next available SB vessel in Gatun Lake is S2 which is a four-loco vessel. Since N8 is a CC vessel, step 9b(2)(a) directs the scheduler to step 7. Vessel 9N is a CC vessel and S2 is not. Using step 7a(1), vessel N8 is delayed at PM for a total of 105 minutes (up to time 550) while awaiting N9 to transit MF and PM locks. During this delay S2 and S3 are scheduled through the Cut, PM and MF locks to the finish of transit since they are both four-loco vessels and the four-loco lanes were assigned to SB vessels. Vessel S4 was

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not scheduled through the Cut since the Cut transit time of 65 minutes for SB vessels would have caused a delay to N8 (S4 would have started Cut transit at time 495. This time plus 65 minutes would have caused a 10 minute delay to N8 since N8 should start transit of the Cut at time 550). Both S2 and S3 are each delayed prior to transit of PM by tie-up along the approach wall while awaiting the lane to become available. After transit of the Cut by S2 and S3, N8 and N9 transit the Cut and Gatun Lake.

Using step 11, N8 and N9 are scheduled through Gatun lock. N8 is available for transit at time 730 but the six-loco lane is not available until time 770 due to the transit of S9 through this lane. When this lane becomes available N8 and N9 are scheduled through Gatun lock. Vessels 10S, 11S, and 12S are also scheduled through the lock in the four-loco lane. Vessel 12S completes transit of the lock at time 915 and N9 completes transit of the lock at time 920. No more NB vessels are available to transit Gatun lock and scheduling of transits at this lock stops.

Since a NB(6) vessel, 7N, is available to start transit at MF lock, step 11b(2) directs the scheduler to step 9b. Scheduling continues in the same manner until all vessels on the ready time list in each direction have been scheduled through all sections of the canal.

C. COMPARISON OF DERIVED AND ACTUAL SCHEDULES

The two schedules are compared using the Marine Traffic Control Scheduling Objectives described in Section II of this report.

The first objective is to maintain the maximum lockage capacity in the lock of least capacity. In order to measure lockage capacity at a lock, the quantity lock dead time was used. Lock dead time is defined as the total number of minutes during the scheduling period in which no vessel was using the lock after the lock transit interval had elapsed. This time is measured as the sum of the elapsed times between the end of the lock transit interval of one vessel and the entrance into the lock lane of the next vessel in either direction. The following lock dead times were computed from both the actual and derived schedules:

TABLE V. LOCK DEAD TIMES

	MF	PM	Gatun	
Actual Schedule	620	1080	65	(mins.)
Derived Schedule	845	560	30	

Utilization of the "lock of least capacity", Gatun lock, was marginally better in the derived schedule. There appeared to be a trade-off in usage between MF and PM locks. However, since the usage of MF and PM locks is probably better represented combined, due to the fact that vessels must transit both locks in sequence, the derived schedule with a total dead time at these two locks of 1405 minutes is better than the actual schedule which has a total dead time of 1700 minutes. This difference is probably due to the fact that the algorithm scheduled vessels through these two locks earlier than in the actual schedule.

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The second objective is to obtain the lowest possible Intransit time and Canal Zone Waters time for each vessel. Intransit times and Canal Zone Waters times for each vessel are shown on the scheduling forms in Appendices D and E. The following statistics were computed for NB and SB vessels from the derived and actual schedules:

TABLE VI. CZW AND INTRANSIT TIMES

| | | CZW Time(min.) | | Intransit Time(min.) | |
		Avg.	S.D.	Avg.	S.D.
Actual Schedule	NB	884	237	420	48.5
	SB	914	393	387	51.2
Derived Schedule	NB	811	229	443	60.6
	SB	966	321	382	59.2

An apparent trade-off was made between NB and SB average CZW times in the actual and derived schedules. Standard deviations seem to favor the derived schedule slightly if decreasing NB average CZW time at the expense of increasing SB average CZW time can be accepted.

The opposite effect is observed on the comparison of Intransit times which seems to favor the actual schedule for the same reason discussed above.

Although conclusions on such a sparse data base are to be avoided, the results seem to indicate that the algorithm favors a reduction in NB CZW times and a general reduction in CZW time standard deviations in both directions at the expense of a slight increase in SB CZW times and Intransit times in both directions.

The total delay time while intransit for vessels in each direction was also computed. In the derived schedule total vessel delays in each direction were easily computed since delays are indicated explicitly on the scheduling form. Vessel delays were not indicated on the TOS. Using vessel beam width, each vessel's Intransit time through the canal with no delays was determined using Table X in Appendix B. This value of Intransit time for each vessel was then subtracted from the actual Intransit times for each vessel obtained from the TOS. The difference was assumed to be each vessel's delay while intransit. Total delays to vessels in each direction while intransit are presented in Table VII.

TABLE VII. DELAY TIMES

		Total Delay Time	
Actual Schedule	NB	1320	(mins.)
	SB	645	
Derived Schedule	NB	1655	
	SB	515	

The actual schedule is obviously superior in regard to total vessel delays. This data also correlates well with that presented in Tables V and VI. Intransit times for vessels in the NB direction are slightly higher in the derived schedule indicating larger delays and Intransit times for vessels in the SB direction are slightly lower in the derived schedule indicating smaller delays. Lock dead times are also less in the derived schedule which seems to indicate that vessels delayed within the canal are more readily available for lockage when a lock becomes available.

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The third objective is to maintain a reasonable balance between NB and SB shipping. The same number of vessels were transited in both schedules, although in the derived schedule the last SB finished later and the last NB finished earlier than in the actual schedule. This could have been resolved by delaying a NB longer in the lake and allowing a SB vessel to transit Gatun lock in its place. This would have had the effect of adding about 60 minutes to the last NB vessel's finish time and subtracting about 60 minutes from the last SB vessel's finish time.

The last objective is to reduce overtime at the locks as much as possible. A study of the actual and derived schedules shows that one lane at each lock could be secured at the following clock times without affecting subsequent scheduling:

TABLE VIII. LOCK SECURING TIMES

	Lock		
	MF	PM	Gatun
Actual Schedule	2140	1940	2305
Derived Schedule	1735	1640	2005

The results in Table VIII using the scheduling algorithm appear markedly better than present scheduling procedures. The reason for this seems to be the algorithm's practice of starting vessel transits earlier and letting vessels take delays in Gatun Lake during transit vice at anchorage prior to transit. This practice decreases dead time at the locks, as indicated in Table V, thereby allowing the securing of one lock lane at each lock much sooner.

Because some of the assumptions made in the derivation of the sched-
uling algorithm affect the comparison between derived and actual sched-
ules it is appropriate to discuss them briefly. The TOS utilized in the
make-up of the actual schedule did not indicate lock locomotive capability
and a (6/4) capability was therefore assumed at all locks. A study of the
actual schedule indicates the certainty of a (6/6) capability at Gatun and
possibly at PM and MF (unless locomotive crew lane switching occurred).
In addition, Relay lockage procedures were evidently used at MF locks al-
though this is also not indicated explicitly on the TOS.

Vessel tug requirements and availability of tugs were not accounted
for although tugs were definitely required for certain vessels.

Tandem pairs were used in the unmodified actual schedule which means
that more vessels (two NB and three SB) actually transited the canal in the
24-hour time span than did in the derived schedule. However, a study of
the actual schedule shows that some vessels transited various sections of
the canal in a shorter time period than the transit time table in Appendix B
would indicate. Thus, the derived schedule, using transit times from Ap-
pendix B, was a very conservative schedule allowing more time than neces-
sary for transit. The fact must be borne in mind that the TOS (from which
the actual schedule was derived) shows the actual times of completed
transits while the derived schedule is only a schedule, using the transit
time table available.

Since vessel speed capability was not indicated on the TOS, transit
times through Gatun Lake were computed on the basis of a ten-knot

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capability giving a 120 minute transit time. Vessel draft and cargo status was also not available and transit time assumptions for all vessels in the Cut and for vessels with greater than 90 foot beam widths were made as indicated earlier in this section of the report.

In summary, the performance of the scheduling algorithm compared quite favorably to current scheduling practices for the particular mix of vessels considered.

None of the assumptions made in the derivation of the algorithm were considered to have been detrimental to the comparison of the two schedules except the assumption of a 6/4 lock locomotive capability when the locks probably had a 6/6 capability. This would tend to falsely favor the actual schedule results over the results obtained using the algorithm.

In the case tested the algorithm fulfilled all MTC scheduling objectives at least as well as the present scheduling practices with exception of obtaining the lowest possible Intransit and CZW times for the particular mix of vessels. However, based on the results of the comparisons between the other measures of effectiveness it would appear that more study of the interactions between these measures is necessary. For instance, the effect of higher vessel intransit delays for the SB vessels may have the effect of reducing CZW times for these vessels as it did for NB vessels. This, however, also has the effect of increasing vessel Intransit times as it did for NB vessels. Reduced CZW times would be considered good for vessel owners as it frees the vessels for revenue producing and reduced Intransit times are considered better for canal operations.

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V. CONCLUSIONS

A. SUMMARY

The scheduling algorithm appears to compare favorably with present scheduling practices although additional testing with other vessel mixes needs to be undertaken. In addition, the measures of effectiveness developed for use in this paper are considered to be valuable tools, not only in comparing schedules, but also in developing and testing new scheduling techniques. These measures of effectiveness seem to correlate very favorably with one another and future study of their interactions is recommended. In this regard, the scheduling algorithm seems to have been effective in reducing CZW times for vessels by increasing intransit delays, and therefore, increasing Intransit times. There appears to be a trade-off between shorter CZW times at the expense of longer Intransit times which could be significant in making scheduling decisions.

The algorithm is considered to be valuable in the way that it approaches the scheduling problem. It helps in avoiding a great many false starts by proceeding in a logical manner with the arrangement of vessels for transit and through the actual scheduling process. This approach could be an excellent training aid for apprentice schedulers and will also provide an excellent base for developing a computer scheduling technique for vessel transits.

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B. MODIFICATIONS NEEDED FOR ACTUAL USE

In order to effectively use the scheduling algorithm in normal canal operations there are several requirements which must be incorporated into it. Procedures must be included for handling eight locomotive vessels and eight locomotive lock capability, clear channel vessels, vessel tug requirements, vessel tandem pairs, locomotive crew switching between lock lanes, the incorporation of the 170 foot beam rule in the Cut and Relay lockages.

Incorporating decision rules within the algorithm for handling eight locomotive requirements and Relay lockages are straightforward and would require only minimal effort as would the inclusion of the beam rule.

Tandem lockages could also be incorporated if a sound decision rule could be formulated as to which vessels should be combined. In actual operation of the algorithm tandem pairs would be handled as single vessels but with increased locomotive requirements.

Procedures for handling clear channel vessels, tug requirements and lock lane crew switching would be much more difficult to incorporate as they involve developing a new set of decision rules for establishing priorities among transiting vessels.

C. SUGGESTIONS FOR IMPROVING THE DATA BASE

Many discrepancies were found between the transit times given in the Table of Transit Times, Appendix B, for scheduling vessels through the canal and the Transit Operations Sheet used in recording the actual transits. It is

recommended that the Table of Transit Times be modified to reflect actual

vessel transit capabilities in order to provide more accurate scheduling

information.

The Transit Operations Sheets were also found lacking in information

with which to form an adequate statistical base for many types of research.

The Transit Operations Sheets should be modified to provide an area to ade-

quately indicate vessel cargo status, vessel draft and lock locomotive

capability. If lock culvert status during each vessel's transit is not avail-

able in other records, it should be included on the TOS so that accurate lock

transit times may be established. In this regard, vessel delays while in-

transit should also be explicitly indicated on the TOS to assist in the com-

pilation of statistics.

VESSEL RESTRICTIONS AND REQUIREMENTS

TABLE IX. TABLE OF VESSEL RESTRICTIONS AND REQUIREMENTS [7]

	RESTRICTIONS				TANDEM WITH HANDLINE LIMIT 750'		REQUIREMENTS TUGS			
	CLEAR CHANNEL	DAYLIGHT TRANSIT	DAYLIGHT IN CUT	CLEARCUT	TANDEM TOTAL LIMIT 800	HANDLINE TOTAL LIMIT 800	LOCKS IN	OUT	CUT 18	LOCOMOTIVES & WIRES
LENGTH OVER 600' — LENGTH OVER 600' — BEAM										
675' BRIDGE AFT	A,B,C	✕	✕	✕	NO	YES[1]	✕	✕		6/12
100' AND OVER	A,B,C&D	YES	YES	YES	NO	YES[1]	2	1	1	8/12
55' TO 99.9'	E	YES	YES	YES	NO	YES[1]	2	1[3]	1	8/12
94' TO 54.9'	E	YES	YES	YES[4]	NO	YES[1]	2	0	1	8/12
85.1' TO 50.5'	NO	YES[6]	YES[6]	NO	NO	YES[1]	1[3]	0	0[6]	6/12
60' TO 85'	NO	NO	NO[9]	NO	NO	YES[1]	1	0	0[6]	6/12
75' TO 79.9'	NO	NO	NO	NO	NO	YES[1]	1[3]	0	0	8/12
UNDER 74.9'	NO	NO	NO	NO	NO	YES[1]	0[6]	0	0	8/12
LENGTH UNDER 600' — BEAM										
85.1' TO 50.5'	NO	YES[6]	YES[6]	NO	YES	YES	1[3]	0	0[6]	4/6[14]
60' TO 85'	NO	NO	NO[6]	NO	YES	YES	1[9]	0	0[6]	4/6[14]
75' TO 79.9'	NO	NO	NO	NO	YES	YES	1[7]	0	0	4/6[4]
UNDER 74.5'	NO	NO	NO	NO	YES	YES	0	0	0	4/6[10]
450' TO 500'	NO	NO	NO	NO	YES	YES	0	0	0	4/4[17]
CARGO										
EXPLOSIVES 1HEXP-A	NO	YES[16]	YES[16]	YES[17]	NO[16]	YES	0	0	0	✕
PROPANE CLASSES 1&2	NO	NO	NO	YES	NO	YES[8]	0	0	0	✕
GASOLINE NAPHTHA 1H2 OR 1HC	NO	NO	NO	NO	YES[8]	YES[8]	0	0	0	✕

A. Gatun Locks to buoys 13 & 14
B. Balboa basin to buoys 13 & 14
C. If maximum draft over 38' Miraflores Locks to buoys 1 & 2
D. Miraflores Locks or from docks to buoys 1 & 2 at night
E. Balboa basin to Thatcher Ferry Bridge

1. Company craft not to exceed 850' total length
2. On request when laden
3. 2 tugs into Pedro Miguel southbound if beam over 87'
4. Yes: If Gatun Lake level over 84' and mean draft over 34'
    If Gatun Lake level under 84' and mean draft over 33'
    If Gatun Lake level under 83' and mean draft over 32'
5. Yes, if mean draft over 36'
6. No, if draft not over 30' and drag is not over 6'
7. Tug on pilot's request
8. Unless authorized for specific ships
9. 350' length limit on vessel with locomotives
10. 650' limit overall with small tankers (GULF KEY and SEATOWN type)

11. No, if waived by Port Captain
12. No, if combined beams do not exceed 170' and cargo is not grade "A" liquid or class 1 & 2 liquified flammable gases
13. 6 wires at pilot's option
14. Length 500.1' to 570' - 4 locomotives 6 wires unless vessel displaces over 25,000 tons, then, 4 locomotives 8 wires
    Length 570.1' to 600' - 4 locomotives 8 wires unless vessel displaces over 30,000 tons, then, 6 locomotives 10 wires, or at pilot's request, 12 wires.
15. Vessel with bow thrusters-tug on request
16. Yes, if XHEXP-B or XHEXP-C
17. If 5 tons or less, may be waived
18. If vessel displaces over 50,000 tons, then, 2 tugs in all locks and one in Gaillard Cut.

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[7] Marine Traffic Control Manual, Panama Canal Company, p70.

VESSEL RESTRICTIONS AND REQUIREMENTS

TABLE IX. TABLE OF VESSEL RESTRICTIONS AND REQUIREMENTS[7]

		RESTRICTIONS					REQUIREMENTS			
						TANDEM WITH HANDLINE LIMIT 750		TUGS		
	CLEAR CHANNEL	DAYLIGHT TRANSIT	DAYLIGHT IN CUT	CLEARCUT	TANDEM TOTAL LIMIT 800	HANDLINE TOTAL LIMIT 800	LOCKS IN	OUT	CUT 18	LOCOMOTIVES & WIRES
LENGTH OVER 900 — BEAM										
675' BRIDGE AFT	A,B,C				NO	YES[1]				6/12
900' AND OVER	A,B,C B D	YES	YES	YES	NO	YES[4]	2	1	1	6/12
95' TO 99.9'	E	YES	YES	YES	NO	YES[4]	2	1[3]	1	6/12
91' TO 94.9'	E	YES	YES	YES[4]	NO	YES[4]	2	0	1	8/12
85.1' TO 90.9'	NO	YES[4]	YES[8]	NO	NO	YES[4]	1[3]	0	0[4]	6/12
80' TO 85'	NO	NO	NO[9]	NO	NO	YES[4]	1	0	0[4]	6/12
75' TO 79.9'	NO	NO	NO	NO	NO	YES[4]	1[7]	0	0	6/12
UNDER 74.9'	NO	NO	NO	NO	NO	YES[4]	0[6]	0	0	6/12
LENGTH UNDER 900 — BEAM										
85.1' TO 90.9'	NO	YES[8]	YES[8]	NO	YES	YES	1[3]	0	0[4]	4/6[14]
80' TO 85'	NO	NO	NO[9]	NO	YES	YES	1[+9]	0	0[4]	4/6[14]
75' TO 79.9'	NO	NO	NO	NO	YES	YES	1[7]	0	0	4/6[14]
UNDER 74.9'	NO	NO	NO	NO	YES	YES	0	0	0	4/6[14]
450' TO 500'	NO	NO	NO	NO	YES	YES	0	0	0	4/4[13]
CARGO										
EXPLOSIVES IMEXP-A	NO	YES[m]	YES[14]	YES[17]	NO[16]	YES	0	0	0	
PROPANE CLASSES 1 & 2	NO	NO	NO	YES	NO	YES[8]	0	0	0	
GASOLINE NAPHTHA IMB OR IMC	NO	NO	NO	NO	YES[10]	YES[9]	0	0	0	

A. Gatun Locks to buoys 13 & 14
B. Balboa basin to buoys 13 & 14
C. If maximum draft over 38' Miraflores Locks to buoys 1 & 2
D. Miraflores Locks or from docks to buoys 1 & 2 at night
E. Balboa basin to Thatcher Ferry Bridge

1. Company craft not to exceed 850' total length
2. On request when laden
3. 2 tugs into Pedro Miguel southbound if beam over 87'
4. Yes: If Gatun Lake level over 84' and mean draft over 34'
   If Gatun Lake level under 84' and mean draft over 33'
   If Gatun Lake level under 83' and mean draft over 32'
5. Yes, if mean draft over 36'
6. No, if draft not over 30' and drag is not over 6'
7. Tug on pilot's request
8. Unless authorized for specific ships
9. 350' length limit on vessel with locomotives
10. 650' limit overall with small tankers (GULF REY and SEATOWN type)
11. No, if waived by Port Captain
12. No, if combined beams do not exceed 170' and cargo is not grade "A" liquid or class 1 & 2 liquified flammable gases
13. 6 wires at pilot's option
14. Length 500.1' to 570' - 4 locomotives 6 wires unless vessel displaces over 25,000 tons, then, 4 locomotives 8 wires
    Length 570.1' to 600' - 4 locomotives 8 wires unless vessel displaces over 30,000 tons, then, 6 locomotives 10 wires, or at pilot's request, 12 wires.
15. Vessel with bow thrusters-tug on request
16. Yes, if IMEXP-B or IMEXP-C
17. If 5 tons or less, may be waived
18. If vessel displaces over 50,000 tons, then, 2 tugs in all locks and one in Gaillard Cut.

Marine Traffic Control Manual, Panama Canal Company, p70.

APPENDIX A

...SAND REQUIREMENTS

...IS AND REQUIREMENTS [7]

...inutes more in the Cut than north-

...slow down approaching Pedro Miguel

0 minutes longer from Cristobal to

nd vessels because moving out of the

,nal time.

are contained in Table XI and depend on

ve requirement and draft.

...waived by Port Captain
...combined beams do not exceed 170' and
...is not grade "A" liquid or class
...liquified flammable gases
...pilot's option
...1' to 570' - 4 locomotives 6 wires
...vessel displaces over 25,000 tons,
...locomotives 8 wires
...' to 600' - 4 locomotives 8 wires
...ssel displaces over 30,000 tons,
...comotives 10 wires, or at pilot's
...2 wires.
...v thrusters-tug on request
...or XHEAP-C
...may be waived
...es over 50,000 tons, then,
...ocks and one in Gaillard Cut.

TABLE X.   CANAL TRANSIT TIMES

Vessel Size Beam In Feet	Balboa entrance to Basin[1]	Basin to Locks[1]	Miraflores Locks Transit	Miraflores Interval regular	Miraflores Interval relay Up	Miraflores Interval relay Down	Miraflores Lake	Pedro Miguel Locks Transit	Pedro Miguel Interval	Gatun Lake[3] speed knots	Gatun Lake[3] time	Gatun Locks Transit	Gatun Locks Interval regular	Gatun Locks Interval relay	Gatun[6] Lock to Lock to Cristobal
90	30	30	35	40	30	30	20	25	35			50	1:00	30	30
50-59	30	30	40	45	30	30	20	25	35			50	1:00	30	35
60-69	30	30	40	50	30	30	25	30	40			55	1:05	30	35
70-79	30	30	45	55	35	35	25	30	40			1:00	1:10	35	
80-89	30	30	50	60	40	40	25	35	45	_Average Gatun Lake_		1:05	1:15	40	
Deeply Laden D 36	30	30	55	1:05	35	40	25	40	50	speed knots	time	1:10	1:20	40	
90-99	30	30	1:00	1:10	40	45	25	40	50	15	1:30	1:10	1:20	40	35
90-99 Laden 36' D 30'	30	30	1:10	1:20	45	50	30	50	1:00	12	1:45	1:20	1:30	45	35
90-99 Deeply Laden 36	30	35	1:15	1:25	50	55	30	55	1:05	10	2:00	1:30	1:40	50	40
100+ Ballast	30	30	1:05	1:15	45	50	25	45	55	8	2:45	1:15	1:25	45	35
100+ Laden 36 D 30	30	30	1:15	1:25	50	55	30	55	1:05	6	3:45	1:30	1:40	55	35
100+ Deeply Laden 36	30	35	1:25	1:35	1:00	1:00	30	1:00	1:10	4	5:30	1:50	2:00	1:00	40
Tandem	30	30	50	1:00	40	40	20	35	45			1:05	1:15	40	35
			(+10 min. if S.W. culvert) 5	(+10 if S.W. culvert both regular & relay) 5				(+5 min. if S.W. culvert) culvert) 5				(+15 min. if S.W. culvert)	(+15 min. if S.W. culvert relay) 5	

1 Subtract 5 min. for southbounds.
2 For southbounds add 5 min.
3 Ships with length 600' or draft 38' average 10 knots.
4 Add 30 min. for southbounds. Their time starts from the anchorage.
5 If centerwall culvert only, double factor added for sidewall culvert only.

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TABLE XI

GAILLARD CUT TRANSIT TIMES

Northbound	(Hours:Minutes)
Any vessel in ballast	1:00
Any vessel with draft under 34 feet	1:00
Any vessel with draft 34 to 36 feet	1:05
Any vessel with draft 36 to 37 feet	1:10
Any vessel with draft 37 feet and over	1:15

Southbound	
4 locomotive vessel in ballast	1:00
4 locomotive vessel loaded	1:05
6 locomotive vessel in ballast	1:05
Draft not over 34 feet	1:10
Draft 34 to 36 feet	1:15
Draft 36 to 37 feet	1:20
Draft over 37 feet	1:25

Figure 5. Diagram of Regular and Relay Lockage Procedure[9]

REGULAR LOCKAGES
GATUN LOCKS

1 - LOCOMOTIVES SECURED SHIP AT TIE UP STATION
2 - SHIP MOVED INTO FIRST LEVEL
3 - SHIP MOVED INTO MIDDLE LEVEL

4 - SHIP MOVED INTO LAST LEVEL
5 - SHIP MOVED OUT OF LAST LEVEL
6 - LOCOMOTIVES OFF - RETURN TO TIE UP STATION
     TO SECURE NEXT SHIP
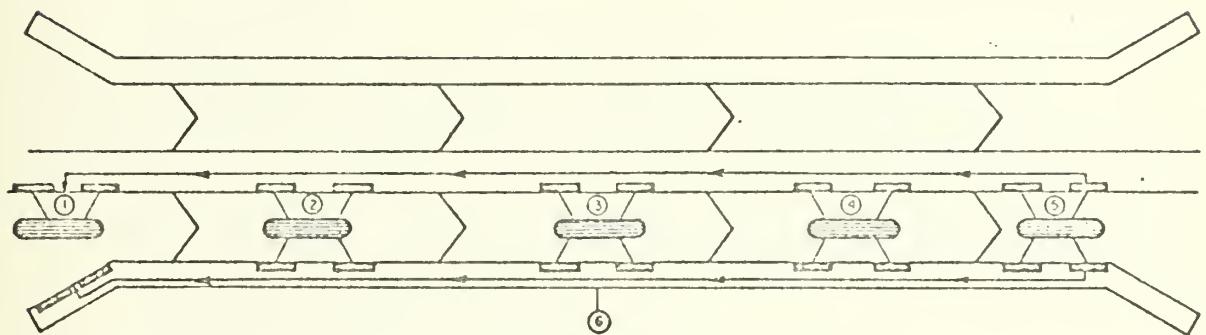
RELAY LOCKAGES
GATUN LOCKS

A FIRST SET OF LOCOMOTIVES
B SECOND SET OF LOCOMOTIVES

1A - LOCOMOTIVES SECURED SHIP AT TIE UP STATION
2A - SHIP MOVED INTO FIRST LEVEL
3A - SHIP MOVED INTO MIDDLE LEVEL
4A - LOCOMOTIVES OFF - RETURN TO TIE UP STATION
       TO SECURE NEXT SHIP

1B - LOCOMOTIVES RELAY AND SECOND SET OF LOCOMOTIVES
       READY TO MOVE SHIP INTO LAST LEVEL
2B - SHIP MOVED INTO LAST LEVEL
3B - SHIP MOVED OUT OF LAST LEVEL
4B - LOCOMOTIVES OFF - RETURNED TO MIDDLE LEVEL
       AND READY TO RELAY NEXT SHIP
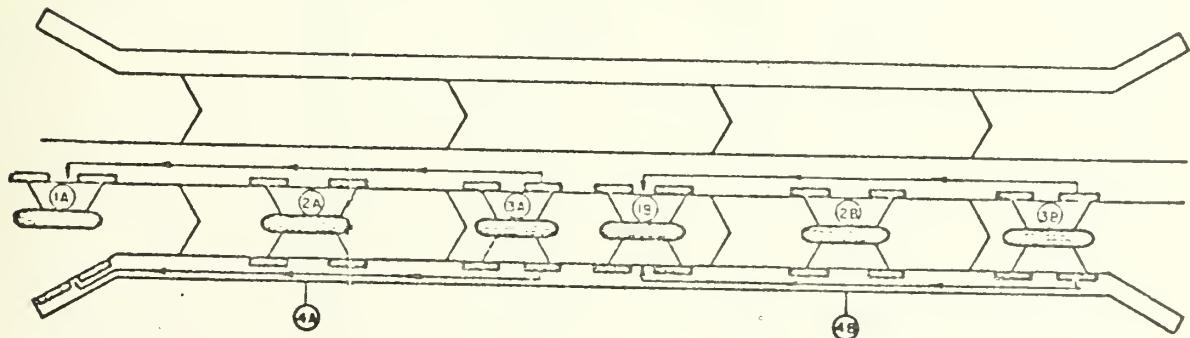
[9] Marine Traffic Control Manual, Panama Canal Company, p83.

Example of Regular Lockage Timing[10]

1. All times are rounded to the next five minutes.

2. Arrival time between two consecutive vessels in the same direction is equal to the Regular lockage interval of the first vessel.

3. Arrival time between the last and first vessel during a change of direction is equal to the lock transit time of the last vessel plus ten minutes.

4. Clearance time is equal to arrival time plus transit time.

5. If only the sidewall culvert is used for filling or emptying the lock chamber, add to the transit or interval times the values indicated in Table X in Appendix B.

6. Lockage intervals and transit times for a given vessel's beam are given in Table X.

TABLE XII

REGULAR LOCKAGE TIMING AT MIRAFLORES LOCK

Beam	Vessel Transit Order No.	Regular Lockage Interval	Transit Time	Arrival	Clearance
53	N1	45 min.	40	0:00	0:40
73	N2	55	45	0:45	1:30
82 Ballast	N3	60	50	1:40	2:30
64	S1	50	40	2:40	3:20
90 ballast	S2	1:10	1:00	3:30	4:30

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[10] Ibid., p. 79.

Example of Relay Lockage Timing[11]

1. All times are rounded to the next five minutes.

2. Lockage transit time for a Relay lockage is the same as for a Regular lockage minus the time to approach tie-up (T/U) station; that is, five minutes for tandems and vessels with beams less than 80' and ten minutes for all other vessels. Clearance time is equal to ready-to-enter time plus Relay lockage transit time.

3. Ready-to-enter time between two consecutive vessels in the same direction is equal to the Relay lockage interval of the first vessel.

4. Ready-to-enter time between the last and first vessel during a change of direction is equal to the clearing time of the last vessel plus ten minutes.

5. Arrival for tie-up time is equal to the ready-to-enter time of the previous vessel in the same direction.

6. If only the sidewall culvert is used for filling or emptying the lock chamber, add to the transit or interval times the values indicated in Table X in Appendix B.

7. Lockage intervals and transit times for a given vessel's beam are given in Table X.

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[11]Ibid., p. 80.

TABLE XIII

RELAY LOCKAGE TIMING AT MIRAFLORES LOCK

Beam	Vessel Transit Order No.	Relay Lockage Interval	Transit Time (Relay Lockage)	Arrival for T/U	Ready to Enter	Clearance
53	N1	30 min.	35		0:00	0:35
75	N2	35	40	0:00	0:30	1:10
82 Ballast	N3	35	40	0:30	1:05	1:45
64	S1	30	35		1:55	2:30
90 Ballast	S2	45	50	1:55	2:25	3:15

APPENDIX D. ACTUAL TRANSIT SCHEDULE

TABLE XIV. MODIFIED ACTUAL SCHEDULE (NORTHBOUND)

NORTHBOUND/ ~~SOUTHBOUND~~ SCHEDULING FORM

TR. ORD.	R.T. ORD.	REMARKS	BEAM	LOCOS	PACIFIC CHANNEL	MF LOCK E( )	MF LOCK W( )	MF LAKE	PM LOCK E( )	PM LOCK W( )	CUT	GATUN LAKE	GATUN LOCK E( )	GATUN LOCK W( )	ATLANTIC CHANNEL	R.T.	I.T. TIME	CZW TIME
1	2		64	4	101-175		175-213	213-225	225-250		250-301	301-415		415-474	474-500	455	300	755
2	3		56	4	126-184		184-245	243-255	253-283		283-335	335-484	484-544		544-565	220	330	795
3	4		60	4	147-212		212-275	275-315			310-375	375-542		542-609	609-630	195	390	790
4	5		74	4	177-247		313-347	315-360			355-414	414-619		619	649-670	101	524	836
5			75	4	232-284		289-352	352-375	315-405		405-466	465-674		674-737	737-762	100	544	505
6	1	CC/DL	27	4	245-345	345-352		332-427	427-450		450-555	655-722	722-770		770-810	720	424	1505
7	8	CC/DL	105	6	325-407		407-454	456-533	433-516		519-580	582-686		686-810	810-858	305	404	732
8	7	DL	90	6	393		483-523	523-515		545-615	527-670	527-732		752-876	876-919	60	414	910
9	14		84	4	510-517		547-645	517-715		675-745	712-774	774-934	934-1001		1001-1024	50	410	955
10	12	DL	117	4	570-575		404-704	704-752		720-790	727-945	945-925		925-1025	1023-1095	35	350	955
11	3		95	4			714-752	750-952		920-945	946-920	950-1011	1102-1163		1146-1171	110	454	1110
12	10		91	4	737-745		788-818	515-870		810-917	717-945	900-1193		1113-1355	1255-1320	30	440	1020
13	15		51	4	515-819		889-934	934-952	952-981		181-1036	975-1243	1243-1312		1312-1325	20	454	515
14	11		71	4			885-934	934-952		1021-1021	1024-1024	1035-1323	1325-1386		1325-1405	202	515	1110
15	13		62	4	865-940		940-951	921-1000				1040-1325			1325-1405	350	445	1172
16	16		63	4	975-1032		1032-1107	1107-1023		1084-1180	1180-1222	1222-1380		1381-1440	1411-1475	535	446	1450

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TABLE XV. MODIFIED ACTUAL SCHEDULE (SOUTHBOUND)

/SOUTHBOUND SCHEDULING FORM

R.T.ORD.	TR.ORD.	REMARKS	BEAM	LOCOS	PACIFIC CHANNEL	MF LOCK E( )	MF LOCK W( )	MF LAKE	PM LOCK E( )	PM LOCK W( )	CUT	GATUN LAKE	GATUN LOCK E( )	GATUN LOCK W( )	ATLANTIC CHANNEL	R.T.	I.T.TIME	CZN TIME
6	1		62	4	485-540	445-495		435-445	411-456		350-411	235-350	184-235		135-184	60	300	450
5	2		61	4	557-614	511-557		432-511	450-482		393-450	259-393		200-259	145-200	60	355	610
4	3		60	4	536-672			521-544	491-521		424-491	310-424	256-310		200-254	60	330	350
9	4		62	4	605-651	544-568		556-546	505-556		432-503	355-432		281-335	235-281	120	325	540
3	5		72	4	721-776	526-623		644-672	630-664		534-636	374-534	323-374		273-323	10	345	690
7	6		80	6	714-774	579-721		724-727	697-704		521-671	401-547		336-401	303-353	00	430	770
3	7	DL/PD	101	6	673-925	723-793		771-772	715-771		637-715	474-637	388-474		332-383	1170	490	1110
1	8	PD	95	6	930-990	744-810		314-340	773-831		683-775	542-683		483-542	402-433	840	445	1530
2	9	PD	93	6	483-1052	790-953		926-926	831-964	928-460	759-831	632-759	501-632		440-501	620	425	1675
12	10		64	4	1059-1115	1103-1059		410-1023			860-923	718-860	648-718		605-848	300	410	515
13	11		84	6	1133-1205	1092-1123		1025-1032	1025-1105		957-1025	850-951	783-850		730-783	615	340	530
10	12		64	4	1246-1303	1202-1246		1103-1202	1090-1103		1020-1080	930-1020	808-930		753-803	120	440	1130
14	13	CC	63	4	1300-1375	1223-1700		1172-1122	1105-1142		1045-1105	972-1045		914-972	855-914	745	335	630
15	14		63	4	1440-1525		1402-1440	1353-1402	1357-1387		1287-1357	1015-1287	1032-1045		950-1032	765	410	760
11	15		64	4	1420-1471		1329-1351	1313-1313	1240-1318		1202-1290	1111-1202		1045-1111	975-1045	180	340	1245
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DERIVED TRANSIT SCHEDULE

TABLE XVI

LIST OF VESSELS IN READY TIME ORDER

Direction	Ready time	Beam	No. of Locos Required	Remarks
Northbound				
1	−760 mins.	27 ft.	4	CC/DL
2	−455	64	4	
3	−220	56	4	MF (W−180
4	−165	60	4	(E−0
5	−140	71	4	
6	−100	75	4	
7	05	90	6	DL
8	35	56	4	PM (W−120
9	70	10 5	6	CC/DL (E−0
10	110	64	4	
11	300	71	4	
12	305	64	4	DL
13	330	62	4	
14	480	84	4	
15	480	51	4	
16	535	63	4	
Southbound				
1	−840 mins.	85 ft.	6	DL
2	−620	88	6	DL
3	−190	10 1	6	CC/DL
4	−180	60	4	Gatun (W−180
5	−60	61	4	(E−180
6	60	62	4	
7	60	80	6	
8	90	72	4	
9	120	62	4	
10	120	64	4	
11	180	64	4	
12	3 00	64	4	
13	675	84	6	
14	745	63	4	CC
15	765	43	4	

TABLE XVII. DERIVED SCHEDULE (NORTHBOUND)

NORTHBOUND/SOUTHBOUND SCHEDULING FORM

TR. ORD.	R.T. ORD.	REMARKS	BEAM	LOCOS	PACIFIC CHANNEL	MF LOCK E(6)	MF LOCK W(4)	MF LAKE	PM LOCK E(6)	PM LOCK W(4)	CUT	GATUN LAKE	GATUN LOCK E(6)	GATUN LOCK W(4)	ATLANTIC CHANNEL	R.T.	I.T. TIME	GZW TIME
1	2		64	4	-60-0	0-40		40-65	65-95		95-155	155-275 (20)		275-330	330-340	455	335	815
2	3		56	4	-10-50	50-90		90-110	110-140		140-200	200-290 (20)		340-390	390-420	220	340	640
3	4		60	4	35-95	95-135		135-180	160-190		190-250	250-370 (30)		400-455	455-485	105	365	650
4	5		71	4	95-145	145-190		180-215	215-245		245-365	205-425 (40)		405-525	525-555	140	330	695
5	6		75	4	120-180		180-225	225-250	250-280		280-340	340-410 (75)		535-575		120	415	725
6	8		50	4	140-200	200-240		240-260	260-290		290-350	350-410 (55)		605-650	635-635	35	455	650
7	10		64	4	175-235		235-275	275-300	300-330		330-390	390-510 (40)		665-720	720-750	110	435	640
8	1	GC/DL	27	6	300-360	360-345		395-415	415-435 (65)		550-610	610-730 (40)	770-820		700-952	700	401	1010
9	9	GC/DL	105	6	340-400	400-475		475-505	505-560		560-620	620-740 (40)	630-920		920-950	70	575	830
10	7	DL	90	4	475-555	465-545		545-5	510-610		610-670	670-790 (40)	930-1000		1000-1030	35	570	1025
11	12	DL	64	4	545-555	555-595		595-620	620-650		650-710	710-930 (45)		925-950	950-1040	305	425	725
12	11		71	4	600-660	660-700		650-615	615-705 (30)		705-765	765-855 (30)		940-1050	1050-1070	300	445	730
13	13		62	4				700-725	925-755 (60)		850-910	810-1030 (50)		1010-1115	1115-1145	330	455	815
14	14		54	4	630-690	690-740		740-765	765-835 (60)		880-920	920-1040 (83)		1125-1190	1190-1220	460	520	740
15	15		51	4	540-750	750-740		740-810	810-840 (30)		870-930	930-1050 (30)		1220-1250	1250-1260	460	520	820
16	16		63	4	740-800	800-840		840-865	865-895		875-955	955-1075 (55)		1220-1315	1315-1345	635	575	810

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TABLE XVIII. DERIVED SCHEDULE (SOUTHBOUND)

NORTHBOUND/SOUTHBOUND SCHEDULING FORM

CZW TIME	I.T. TIME	R.T.	ATLANTIC CHANNEL	GATUN LOCK E(6)	GATUN LOCK W(4)	GATUN LAKE	CUT	PM LOCK E(6)	PM LOCK W(4)	MF LAKE	MF LOCK E(6)	MF LOCK W(4)	PACIFIC CHANNEL	LOCOS	BEAM	REMARKS	TR. ORD.	R.T.ORD.
745	335	-150	420-630	180-235		255-355	355-420		420-470	430-475	755-805	475-515	515-565	4	60		1	4
675	375	-40	130-190		190-245	245-505	565-430		430-445	440-515		515-565	565-615	4	61		2	5
635	370	60	185-245	245-300		300-420	420-495		445-560	470-565	745-805	555-615	615-665	4	62		3	6
635	495	60	250-310	310-375		375-495	630-645	675-720			730-755		805-855	6	63	PL	4	7
745	480	60	335-525	335-450		450-575	640-705	715-780			820-545		515-505	6	33	PL	5	1
545	445	-420	420-420	40-525		545-675	650-715	745-810			825-925	925-1010	425-475	6	101	79/CL	6	2
1250	475	-170	475-535	535-225		625-745	715-840	540-975			935-920		1010-1060	6	72	PL	7	3
945	370	40	575-635	635-645		495-815	515-1035	945-975		960-1080	175-1080		1005-1105	4	62		8	8
485	350	370	645-705	705-700		760-880	550-945		970-1022	1040-1050	1080-1025		1005-1115	4	64		9	9
495	335	120	670-730		730-850	735-905	905-910			1065-1090	1025-1065		1045-1115	4	64		10	10
1000	635	180	735-745		745-850	850-970	970-1035	1100-1130		1130-1155	970-1130		1130-1180	4	64		11	11
545	335	300	800-840		800-915	975-1035	935-1100	1120-1275		1245-1320	1155-1195		1145-1245	4	84		12	12
745	355	676	950-1010	1010-1075		1075-1195	1145-1260	1275-1355		1320-1390	1155-1195		1370-1420	6	63		13	13
725	335	745	1025-1055	1045-1145		1140-1260	1260-1325	1370-1420		1755-1390	1320-1370		1420-1470	4	63	CC	14	14
770	335	766	1040-1150	1150-1205		1205-1325	1325-1390	1370-1420		1420-1445	1380-1420		1455-1535	4	43		15	15
																	16	

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

   This thesis presents an algorithm for scheduling vessel transits through the Panama Canal together with a compilation of current Marine Traffic Control scheduling practices. The performance of the scheduling algorithm is compared with the results of an actual transit schedule using the Panama Canal Company Marine Traffic Control scheduling objectives and additional measures of effectiveness derived in this paper.

20. (con't.)

The interaction between these measures of effectiveness is discussed as pertains to their future use in the efficient scheduling of vessels through the canal.